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AN
INTRODUCTION
TO
NATURAL PHILOSOPHY.

VOL. II.

A N
INTRODUCTION
TO
NATURAL PHILOSOPHY.

ILLUSTRATED WITH COPPER PLATES.

By WILLIAM NICHOLSON,

Non enim me cuiquam mancipavi, nullius nomen fero : multum
magnorum virorum iudicio credo, aliquid et meo vindico. Nam illi
quoque, non inventa, sed quaerenda, nobis reliquerunt. SENECA.

IN TWO VOLUMES,

VOL. II.



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SECOND VOLUME.

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B O O K II.

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Of Fluids.

WHEN we reflect on the structure of the universe, we may observe, not only that the world and its inhabitants are mutually formed for each other; but likewise, that those actions which most constantly accompany the changes in bodies, are selected as the means by which intelligence from without is received by the senses. The motion of light is chosen to give us notice of the existence of bodies which are not immediately accessible, and the motion of the fluid air; by which we are surrounded, is made the object of a sense whose advantages are too obvious to need enumeration,

namely, the hearing. The first has already been spoken of, and regularity directs our attention to the second: for which purpose we shall first take a cursory view of the general properties of fluids, and next proceed to illustrate those of the air.

C H A P. I.

Of Hydrostatics; or the Effects which arise from the Gravity of Fluids.

A FLUID is a body whose parts readily yield to any impression, and in yielding, are easily moved amongst each other.

The cause of fluidity is not perfectly known. Some are of opinion that the particles of fluids are spherical, and, in consequence of their touching each other in few points, cohere very slightly, and easily slip or slide over each other. But that the particles of fluids are of the same nature or figure as those of solids, appears from the very frequent conversion of the one
into

into the other. It does not seem rational to suppose that the particles of gold, lead, glass, &c. when in fusion, are rendered spherical by the action of the fire, and when that action ceases, that the particles resume their former, perhaps cubical, figure, as the bodies become solid by cooling. Neither can we imagine, with any degree of probability, that the particles of water are changed by cold, when it becomes a solid and brittle lump of ice, and are again reinstated in their original form, when the ice, by dissolution, is again turned to water.

The cause of fluidity, then, does not appear to depend on the figure of the particles, but probably on their smallness and want of cohesion.

If the particles of a body cohere strongly together, it is evident that they will not easily move amongst each other. An imperfect cohesion must therefore be one of the properties of a fluid mass; and that the smallness of the particles is requisite to fluidity will appear by considering, that the surface of a body composed of small particles must be much

more smooth and even than the surface of a body composed of larger particles : that two flat bodies may be conceived to consist of particles so small, that their surfaces shall differ insensibly from perfect planes : that these bodies, if placed on each other, will slide without the least sensible friction : and that if the particles of these bodies thus placed on each other be, by any means, deprived of the whole or the greatest part of their cohesion, the bodies will not only slide on each other in the just mentioned plane, but the parts of the mass will also slide on each other in any other direction whatsoever. Consequently they will readily yield to any impression, and in yielding, be easily moved amongst each other. That is, they will constitute a fluid mass.

If the particles of a body be without cohesion, they yield to an impressed force ; but if, at the same time, they be not sufficiently minute, the mass is deprived of the second circumstance of the definition ; for the parts do not easily move amongst each other. Such are powders ; which nevertheless,

less, yield more readily, the smaller the particles are of which they are composed.

It is not practicable to reduce a solid body to a fluid by pulverizing ; for, however fine the powder may be, the cohesion of its parts prevents their easily moving among each other. But, if this cohesion be diminished by heat or otherwise, pulverized bodies may resemble fluids. Thus, fine powder of alabaster, or plaister of Paris, heated over the fire in a flat dish, will be agitated in great waves like a boiling fluid, and may be stirred with a stick or ladle, without affording the resistance it did when cold. And a dish of sand placed on the head of a drum which is briskly beaten, will, in almost every particular, imitate the properties of a fluid ; heavy bodies will immediately sink in it to the bottom, light bodies will emerge to the top, and if an hole be made in the side of the dish, the sand will spout forth like water.

That science, which treats of the effects which arise from the weight of fluids, is called hydrostatics.

The parts of fluids are heavy; but because the upper parts rest upon, and are sustained by, the parts beneath, and because, by the property of fluids, the parts are readily moved in all directions, upwards as well as downwards, they do not at first consideration appear to be heavy.

The bottom of an upright prismatical or cylindrical vessel is pressed by the whole weight of the fluid contained; and as the weight of the fluid is in proportion to its height, so is likewise the pressure. Thus in the cylinder AB (fig. 95.) when filled to C, the bottom is pressed by, or sustains a certain weight, suppose one pound; if it be filled to D, the pressure becomes two pounds; if to A, three pounds, &c.

The whole of any fluid mass may be imagined to consist of a number of columns of an inconsiderable thickness, which stand perpendicularly on the base of the containing vessel, and press the same with their respective weights. The pressure, then, if the height remain the same, is as the number of columns, and this number is as the area of the base. Consequently in vessels whose bases differ

differ as to area, and which contain fluids of the same density, but different heights, the pressure will be in the compound ratio of the bases and heights; that is, as the area of the base multiplied by the height of the fluid in one vessel, is to the area of the base multiplied by the height of the fluid in the other vessel, so is the pressure sustained by the base of the one, to the pressure sustained by the base of the other vessel.

In like situations, the pressures of fluids will be as their densities.

The densities being discoverable only by the different weights of bodies of the same bulk, the comparative densities of bodies are therefore called their specific gravities.

If the columns of which a fluid mass was supposed to consist, were formed of particles lying in strait perpendicular lines, the pressure of the fluid would be exerted on the bottom of the vessel only; but, as they are situated in every irregular position, there must, of consequence, be a pressure exerted in every direction; which pressure must be equal at equal depths. For if any part of the whole mass were not equally pressed on all

fides, it would move towards the side on which the pressure was least; and would not become quiescent till such equal pressure was obtained. The quiescence of the parts of fluids is therefore a proof that they are equally pressed on all sides.

On this account it is, that fluids, as far as they are not prevented by external accidents, do always conform their upper surface to the plane of the horizon. For if any column or part of the fluid be elevated above the rest, its lateral pressure will cause the elevated part to spread sideways over the surface, till it becomes uniformly of the same height, or horizontal.

The equal pressure of fluids in every direction, being understood, is used to account for many phenomena which happen to them in different circumstances; some of which are the following.

The horizontal bottom of a vessel is pressed by, and sustains no more nor less than the weight of a column of the fluid it contains, whose base is the bottom itself, and whose height is that of the fluid.



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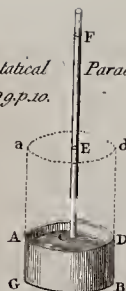
Pressure of Fluids. Fig. 98. p. 9.



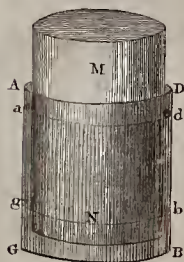
*Pressure of Fluids.
Fig. 98. p. 9.*



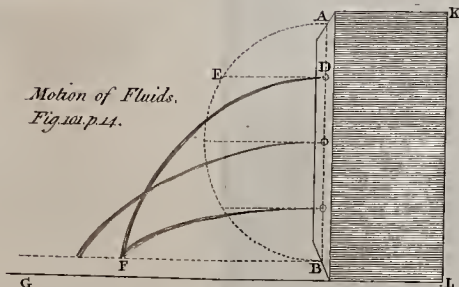
*Hydrostatical
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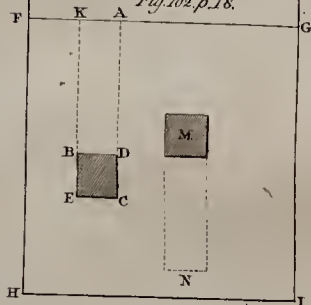
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*Motion of Fluids.
Fig. 101. p. 14.*



*Bodies immersed in Fluids.
Fig. 102. p. 18.*



*Arcometer
or
Hydrometer.
Fig. 103. p. 25.*



*Arcometer
or
Hydrometer.
Fig. 104. p. 27.*



In the vessel ECDF (fig. 96.) the bottom CD sustains no more than the column ABDC. For the other parts of the contained fluid can only press the column ABDC laterally, and therefore contribute not at all to the increase of the weight or pressure on the bottom CD; but rest intirely on the sides EC and FD.

Also in the vessel ECDF, (fig. 97.) the bottom EF sustains a pressure equal to the weight of a column whose base is EF, and height equal to CA. For the pressure at AB is equal to the weight of the column ABCD, and its lateral pressure, which is equal to the same weight, must cause the parts between EA and BF to press the bottom with an equal force in proportion to the surfaces they cover. Consequently, the effect will be the same as if the whole fluid were of the height CA.

From these two cases combined, the reason is evident, why fluids contained in the several parts of vessels, as A and B, (fig. 98.) remain every where at the same height. For the lowest part at which they communicate, may be regarded as the common base;

base; and the fluids, which rest thereon, are in equilibrio then only, when their heights are equal, however their quantities may vary.

The hydrostatical paradox, as by some it is called, depends on the equal pressure of the parts of fluids every where at the same depth. It is this.

Any quantity of fluid, however small, may be made to counterpoise and sustain any weight, how large soever.

Let ABDG (fig. 99.) represent a cylindrical vessel, to the inside of which is fitted the cover C, which, by means of leather at the edge, will easily slide up and down in the internal cavity, without permitting any water to pass between its edges and the surface of the cylinder. In the cover is inserted the small tube CF, which is open at top, and communicates with the inside of the cylinder beneath the cover at C. The cylinder is filled with water, and the cover put on. Then, if the cover be loaded with the weight, suppose of a pound, it will be depressed, the water will rise in the tube to E, and the weight will be sustained. If another pound be added, the water will rise to F, and the
weight

weight will be sustained, and so forth, according to the weight added, and the length of the tube. Now, the weight of the water in the tube is but a few grains; yet its lateral pressure serves to sustain as much as the weight of a column of water, whose base is equal to that of the cylinder, and height equal to that in the tube. Thus, the column EC produces a pressure in the water contained in the cylinder, equal to what would have been produced by the column AadD; and, as this pressure is exerted every way equally, the cover will be pressed upwards with a force equal to the weight of AadD: consequently, if AadD would weigh a pound, EC will sustain a pound. And the like of other heights and weights. And by diminishing the diameter of the tube, any quantity of water, how small soever, will, in theory, sustain any weight, however large.

The same may be shewn simpler, thus;

Let AGBD (fig. 100.) represent a hollow cylinder, and MN a cylinder of wood, which nearly fills its cavity. In the cylinder, suppose a little water, whose surface is gb; then, if the wooden cylinder be put into the hollow

one, the water will rise between the surfaces to a and d, and the wood will be sustained floating. The nearer the wooden cylinder approaches to the size of the cavity, the less water is necessary for the experiment.

C H A P. II.

Of the Motion of Fluids which arises from the Pressure of their superincumbent Parts.

THE pressure of fluids being shewn to be in proportion to their depths, it will be easy to find the celerities with which they spout forth from apertures in the bottoms or sides of vessels.

For the motion produced in the fluid must follow the same proportion as the pressure. (Law. 2. p. 25. vol. i.) The quantity of this motion is the product of the quantity of the fluid emitted, multiplied by the velocity. Now, the quantity of the fluid emitted is as the velocity with which it spouts forth. If the velocity be double, a double quantity is emitted; if treble, a treble quantity. Whence it follows, that the quantity of mo-

tion (which in the one case is as the double velocity multiplied by the double quantity emitted; in the other case, as the treble velocity multiplied by the treble quantity, and the like for other degrees of velocity) is as the square of the velocity. The motion being as the depth of the fluid, so must therefore be the square of the velocity. The velocity itself then is as the square-root of the depth.

The velocities of falling bodies are governed by the same ratio; for the squares of the times are as the spaces described, and the velocities are as the times. Whence the velocities are as the square-roots of the spaces described by the falling bodies. And, since at the beginning of motion the velocity of a falling body is the same with that of the uppermost parts of a fluid, both endeavouring to descend by the mere force of gravity; it follows, that the velocity of the fluid which spouts forth at any aperture, beneath the surface of the fluid contained in any vessel, is equal to the velocity which a body would acquire by falling through a space equal to the distance

distance between the aperture and the surface.

And this velocity is such as in an equal time would carry the body uniformly through a space double to that which it had before described from the beginning of its motion. For the last velocity BC, (fig. 4.) with the time AB, will form a parallelogram equal to twice the triangle ABC.

Let AKLB (fig. 101.) represent a vessel which is constantly kept full of water. On the perpendicular side AB describe the semicircle AEB, and from any point D in the line AB draw the horizontal line DE, meeting the circle in E. Then, if an aperture be made in the vessel at D, so that the water may spout forth in an horizontal direction, it will fall on the level plane LG, on which the vessel is placed, at F, and the distance BF shall be twice the length of the line DE.

For AD is equal to half the horizontal space the emitted fluid describes in the time a body would fall from A to D; and the times of falling bodies are as the square-roots of the spaces through which they pass: therefore,

As

As the time, which is expressed by the square root of AD,

Is to half the space which the emitted water describes in that time, to wit, the line AD,

So is the time the water employs in falling from D to B, which is expressed by the square root of DB,

To half the space described by the horizontal motion of the emitted water in that time, namely, the line DE,

Whence it * appears, that DE is a geometrical mean proportional between AD and DB: and that the readiest method of calculating the distance is to multiply the height of the water above the orifice by the height of the orifice above the plain, and the square-root of the product will be half the horizontal distance to which the water will spout. And

* It may, perhaps, be a satisfaction to the Tyro to see an illustration of this.

Let $a = AD$, $d = DB$ and $x = DE$.

Then the above proportion is

Which gives the equation -

Square it

Divide by a

Extract the square-root -

$$\left| \begin{array}{l} a^{\frac{1}{2}} : a :: d^{\frac{1}{2}} : x \\ a^{\frac{1}{2}}x = ad^{\frac{1}{2}} \\ ax^2 = a^2d \\ x^2 = ad \\ x = \sqrt{ad} \end{array} \right.$$

the line DE (by 13. e. 6.) will terminate in the circle's periphery. The distance therefore will be greatest when the water issues from an aperture at the center C; and equal from apertures equally distant above or below the center, as from D and d.

Since the velocity of water, which is emitted from any vessel, is equal to the velocity which a body would acquire by falling from the height of the surface to the aperture, it is plain, that if it spout forth in a direction perpendicularly upwards, it will proceed, with a motion uniformly retarded, to the height of the surface, and then fall again by its own weight. If it spout forth, in a direction obliquely upwards, its velocity being known, its motion must be compounded with the motion produced by the perpendicular action of gravity, by which it will be found to move in the curve of a parabola, as other projected bodies do, whose perpendicular height will vary according to the obliquity of the direction of the fluid.

On these considerations depends the performance of fountains; for the construction of which there is provided a reservoir, elevated considerably

considerably above the plane in which the fountain is to be made. A pipe, communicating with the reservoir, is conveyed to the middle of a basin, and by means of a perpendicular spout, called the *adjutage*, throws the water up in the air to a height which is in the level of the surface of the water in the reservoir.

But in applying these observations to practice, there are many circumstances that, like friction in mechanical engines, tend to diminish the quantities of motion. There are few fluids that have not a considerable degree of cohesion or tenacity, which prevents their parts from moving as freely as otherwise they would have done; and the friction against the sides of tubes very much retards the motion of the included fluids, if the tubes be small or crooked, and the velocity great. In fountains, especially where the fluid is thrown perpendicularly upwards, the part which is falling rests upon the column which ascends, and prevents its arriving at the height to which its motion would have carried it; besides which, the resistance of the air, and other causes, join to the same

VOL. II. C effect.

effect. We must not therefore expect in these organs, more than in any others, that the performance will equal the theory ; yet, it is not difficult to make the proper allowances, so as to find their real effects by calculation ; but our purpose, being general, does not extend to the variety of particulars which offer themselves.

C H A P. III.

Of Specific Gravities.

IF a solid body be plunged in a fluid it will be pressed on all sides, but not equally. Let DBCE (fig. 102.) represent a solid body, immersed in the fluid contained in the vessel FGIH, then the sides DE and BC will be equally pressed ; the upper surface DB will be pressed with the weight of a column, whose base is DB, and height AB, and the under surface will be pressed upwards with a force equal to the weight of a column AC. The body will therefore be impelled upwards with a force equal to the excess of AC above BC ; that is,

is, with a weight equal to that of a column of the fluid whose length is BC. Whence it appears, that every prism, whose axis is perpendicular to the horizon, will, if it be immersed in any fluid, be impelled upwards by a force which is equal to the weight of a quantity of the fluid of the same bulk with the prism. And since any solid whatsoever may be conceived to be formed of an indefinite number of such prisms, it is evident that the rule is true of all bodies, without respect to figure.

But as all bodies, by the force of gravity, tend downwards, it depends upon that gravity, whether the immersed body shall ascend or descend. If the weight of the body exceed that of an equal bulk of the fluid, it will descend; and on the contrary, if the weight of the body be less than that of an equal bulk of the fluid, the above-mentioned pressure will prevail, and it will ascend; if both be precisely equal, the body will remain at rest any where in the fluid.

These things being considered, it appears that any body, how heavy soever, may be made to swim, or any body, how light soever,

to sink, if means be used to keep off the pressure of the fluid on the one or other side, as circumstances require: for, if $ABDK$ be supposed to represent an open tube, instead of a column of the fluid, and the body $DBCE$ be applied close to its lower orifice, so that the fluid may not enter the tube, the pressure on DB will be taken off, and consequently the body will be pressed upwards with a force equal to the whole column AC . If that column be of sufficient length, that is, if the body be immersed sufficiently deep, the pressure will exceed the gravity of the body, and therefore sustain it. In like manner, if M be a body applied to the open end of a tube, which is closed at N , the inferior pressure being taken off, the body will sink by means of the pressure on the superior surface.

Since the pressure by which bodies immersed in fluids are impelled upwards is in proportion to their bulks, it is plain that bodies of equal bulks will lose the same quantity of absolute weight when immersed in fluids of equal density. Whence we have an exact method of determining the bulks of bodies whose

whose weights are known, and from thence finding their specific gravities. For their bulks being as the weights they lose in the fluid, it follows,

As the bulk of one body (or the weight it loses by immersion)

Is to its mass of matter, (or absolute weight)

So is the bulk of any other body (or the weight it loses by immersion)

To the mass of matter (or absolute weight) it would have, if of the same specific gravity with the first body. Which weight last found being compared with the real weight of the latter body, shews the proportion of their specific gravities.

For example; if 34 oz. of lead be weighed in water, and the diminution be 3 oz. and 15 oz. of tin be also weighed in water, and the diminution appear 2 oz. it is required to determine the proportion of their specific gravities. For which purpose,

As the diminution in the lead 3, is to its weight 34, so is the diminution in the tin 2, to the weight of a mass of lead of the same bulk $22\frac{2}{3}$ oz. which is to 15 as the specific

gravity of lead is to that of tin, that is to say, in lower terms, nearly as $11\frac{1}{3}$ to $7\frac{1}{2}$.

But it is more usual and convenient to make rain-water the standard, and refer the other substances to it: thus, in the instances just mentioned, the weight of a mass of water equal in bulk to the lead is 3 oz. lead is therefore to water as 34 to 3, or as $11\frac{1}{3}$ to 1, and in like manner, tin is to water as 15 to 2, or as $7\frac{1}{2}$ to 1.

When the solid is lighter than the fluid in which it is weighed, an additional body of greater density may be joined to it: for instance, suppose a piece of cedar-wood, weighing 92 dwts. were required to be weighed; join to it, by means of a small hair or thread, a piece of lead, whose weight in water is known, and weigh them immersed together. The lead will then appear to weigh less by 58 dwts. than it did without the addition of the cedar; from whence it is evident, that the cedar is impelled upwards by a force that exceeds its own weight by that quantity, or, in other words, that a quantity of water, equal in bulk to the cedar, will weigh 92+58, or

150 dwts. consequently the specific gravities of water and cedar are in proportion as 150 to 92, or in lower terms, as 1 to $\frac{6}{10}$ nearly.

If the adjustment in this experiment be not quickly made, the water imbibed by the wood will render it specifically heavier than before. In fact, wood is not specifically lighter than water, but by means of the air-vessels which run through its substance.

The best method to discover the specific gravities of fluids is, to weigh the same substance in different fluids; and because the diminution it suffers in weight is equal to the weight of a quantity of the fluid which is of the same bulk, we thence obtain the weights of equal quantities of different fluids, and the specific gravities are as those weights; thus, if a piece of glass weighed in oil of vitriol, lose $42\frac{1}{2}$ dwts. and when weighed in water only 25 dwts. their specific gravities will be as those numbers, or in lower terms, as 1 $\frac{7}{10}$ to 1.

In all these experiments, very nice scales must be used, and the body to be immersed must be suspended from one of the scales, by a

horse-hair or fine thread, whose weight is inconsiderable. This branch of physiology is replete with many useful and entertaining experiments, by means of which the foregoing conclusions may be found in different manners. The following, though not quite so exact in practice as those already mentioned, deserves to be noticed, on account of its convenience and simplicity.

When a body floats at the surface of a fluid, the quantity of the fluid, which is displaced by the part immersed, is equal in weight to the floating body. For since the body presses downwards with its whole weight, it must sink till the pressure, which the fluid exerts upwards, is equal to that weight. In this situation, suppose the fluid to be congealed, and the solid then removed: a cavity will be left in the fluid corresponding in form and magnitude with the immersed part of the solid. Let this cavity be filled with a quantity of the same fluid, so that its surface may be level with the rest, and the whole fluid then thawed. The fluid which occupies the place
of

of the solid will then be pressed upwards with a force equal to that sustained before by the solid, namely, equal to the weight of the solid. But it is not moved by that force, for the surface continues level, as before the thaw. The last mentioned quantity of fluid must therefore press downwards with an equal force. That is to say, the weight of a quantity of fluid equal in bulk to the immersed part of a solid which floats on its surface, is equal to the whole weight of the solid.

By the same argument, it follows, that if a floating body be loaded with weights, so as to cause it to sink deeper in the fluid, the additional parts immersed will in bulk be equal to, or displace, parts of the fluid, whose weights are equal to those with which the floating body was loaded.

By these principles is constructed the areometer or hydrometer, which is as follows. AB (fig. 103.) is a tube of glass which is joined to a hollow ball C, at the bottom of which is a smaller ball D. In the cavity D is placed a quantity of quicksilver, by which
the

the instrument is so poised, that it swims in proof spirits of wine immersed to the point M. Therefore a quantity of proof spirits equal in weight to the whole instrument, will be equal in bulk to the immersed part. If it be immersed in another liquid whose specific gravity is greater, it will swim with the tube higher out of the water, suppose to the point B. Then the weights of the quantities displaced remaining the same, their bulks will be as the immersed points of the hydrometer, and the specific gravities of the fluids will be inversely as those bulks. The proportion which any length of the tube bears to the whole bulk of the instrument being known, it will not be difficult to graduate the tube so as to indicate the specific gravities by inspection.

But this instrument is very confined in its use; for if the liquors differ considerably in specific gravity, they will exceed the limits of the graduation: thus the hydrometer which is adapted for spirits, will swim in water with part of the ball above the surface; and if it be adapted to water, it will not swim in spirits

spirits at all. It is true this may be remedied, either by lengthening or widening the tube : but the first is inconvenient, and the latter would make the graduations so short, as to render them of no use. /

To make this instrument of more service, there has been added a little plate or dish DD (fig. 104.) at the top of the tube, upon which may be placed weights, as convenience requires. For example, if the whole instrument float immersed in spirits to the point M, it will require an additional weight to sink it to the same depth in water. Suppose the instrument to weigh 10 dwts. and to be adjusted to rectified spirits of wine, it will then require the addition $1\frac{6}{100}$ dwt. to sink it to the same point in water. Consequently it appears, that the specific gravity of water is to that of spirits of wine, as $11\frac{6}{100}$ to 10, or in lower terms, as 1 to $\frac{86}{1000}$.

This is the best hydrometer, both in respect to exactness and facility in practice. That which is used by the officers of Excise, is very well adapted for its purpose, which is more confined : it differs from that here described,

described, by having its additional weights screwed on at a stem at E. It is most convenient that these instruments should be made of copper.

Here follows a list of the specific gravities of bodies, extracted from the writings of the best modern philosophers.

METALS.		TRANSPARENT BODIES.		MISCELLANEOUS.	
Refined Gold	- -	Diamond	- -	Bismuth	- -
English Guinea	-	Glas of Antimony	-	Cinnabar natural	7300.
Quicksilver	- -	Pseudo-Topazius	-	Cinnabar factitious	8200.
Lead	- - -	Cryſtal Glas	- -	Lapis Calaminaris	5000.
Refined Silver	-	Green or common glaſs	2620.	Hematites	- -
Copper from Japan	9000.	Rock Cryſtal	- - -	Turbith Mineral	8235.
Copper from Sweden	8843.	Iland Cryſtal	- - -	Bohemian Grenate	4360.
Hammered Braſs	-	Selenitis	- - -	Jasper	- - -
Caſt Braſs	- - -	Amber	- - -	Sulphur	- - -
Elaſtic Steel	- -	RAIN WATER	- -	Human Blood	-
Soft Steel	- - -	Rectified Spirits of Wine	866.	Marble	- - -
Iron	- - -	Etherial Spirits of Wine	732.	Nitre	- - -
Pure Tin	- - -	Air	- - -	Wax	- - -
	19640.		3400.		9700.
	18888.		5280.		7300.
	14019.		4270.		8200.
	11344.		3150.		5000.
	11091.		2620.		4360.
	9000.		2650.		8235.
	8843.		2720.		4360.
	8349.		2252.		2666.
	8100.		1040.		1800.
	7820.		1000.		1040.
	7738.		866.		2704.
	7645.		732.		1900.
	7471.		1 $\frac{1}{4}$.		995.

C H A P. IV.

Of the Resistance which Fluids make to Bodies moving in them.

WE must not conclude the general account of fluids, without explaining the resistance they make to the motions of bodies immersed in them. The phenomena which this resistance produces are continually offering themselves to our notice, and appear in every motion that passes under our observation.

When a body is immersed in a mass or quantity of fluid matter, and is in motion, it must separate the parts of the fluid from each other as it moves. If the parts of the fluid be without cohesion or tenacity, this separation will be attended with no difficulty; but if the tenacity be considerable, it will require a considerable force to overcome it. A part of the motion must therefore be lost in producing this effect. And, in the same
 I fluid,

fluid, the more parts are divided in a given time, the greater quantity of the motion must be lost or employed for that purpose. But a body, moving through an uniform fluid, divides a greater or less number of its parts, in proportion as the velocity of its motion is greater or less. Consequently, the resistance which an uniform fluid makes, by reason of its tenacity, to a body immersed and moving in it, is in proportion to the velocity of the moving body.

But there is another resistance of greater consequence, which fluids make to bodies immersed and moving in them, and which arises from the inertia of their parts. Thus, if a body of a given magnitude be moved in a fluid, it must give motion to a certain quantity of that fluid, and the reaction of that quantity will destroy part of the motion of the body. Now a body moving through an uniform fluid, gives motion to a greater or less number of its parts, in proportion to the velocity of its motion, and is therefore resisted in the simple proportion of the velocity on that account. Again, a body moving through an uniform fluid, communicates a greater or
less

less quantity of motion to each of its parts, in proportion to the velocity of its motion, and is therefore resisted in the simple proportion of the velocity on that account. On both accounts, then, the resistance which arises from the inertia of the fluid, is in the duplicate proportion of the velocity of the moving body.

When the same body is spoken of, the resistance and retardation follow the same ratio; but, in different bodies, they differ in the same manner as motion and velocity. Resistance signifies the quantity of motion, and retardation the quantity of velocity which is destroyed: for example, if a body move with a given velocity in a fluid, and lose half its motion by the resistance, its retardation will be half its velocity: but if another body of the same bulk, but twice its weight or mass of matter, move with a like velocity in the same fluid, it will be equally resisted; but, having twice the quantity of motion, will only lose one-fourth of its velocity. Thus, though the resistances be equal, the retardation in the latter instance is only half the quantity of that in the former.

In fluids which are not glutinous, the resistance arising from their tenacity is inconsiderable, especially in swift motion : in which case, the resistance from the inertia increasing as the squares of the velocities, while that from the tenacity increases only as the velocities themselves, the proportion of the latter to the former, becomes so small that it may be neglected. It is usual, therefore, to neglect that resistance which arises from the tenacity of fluids.

In like circumstances, the resistances of fluids are as their densities. For the quantity of matter to be moved is in that proportion.

If a cylinder be moved through an uniform fluid in the direction of its axis, it will suffer a resistance equal to that of a sphere, whose diameter and velocity of motion in the same fluid are equal to those of the cylinder. For proof of which, suppose the cylinder to be quiescent in the middle of a prismatic canal or tube, its axis coinciding with that of the tube. Let this tube be filled with the fluid, and conceive the fluid to be moved through it with a given velocity. Then the

VOL. II. D fluid

fluid will pass between the sides of the tube and the cylinder, and its motion will be impeded by its being reduced to pass through a narrower space. If the sphere be substituted in the place of the cylinder, the space through which the fluid is reduced to pass will be precisely the same, and consequently its motion will be equally impeded. And, because action and reaction are equal, the cylinder and sphere in these circumstances will be equally acted upon by the fluid. Now, let the fluid be supposed quiescent, and the cylinder or sphere moved with the same velocity, and in the contrary direction to that in which the fluid was before moved; and the relative motions of the fluid and immersed body will be the same as before. Consequently the cylinder and sphere, if moved with equal velocities through a prismical vessel containing a fluid, will be equally acted upon in the contrary direction to their motions; that is, they will be equally resisted.

In like manner, it is shewn, that all bodies whose * orthographic projections taken by rays in the direction of their motions, are

* The shadow of a body which is made by the inter-equal,

equal, will be equally resisted when moving in a prismical vessel which is filled with a given fluid. For they equally impede the passing or relative motion of the fluid. And, since this equality of resistance does not at all depend on the magnitude of the prismical vessel, the doctrine may be applied to bodies moving in an indefinitely extended fluid, or fluid contained in an indefinitely large prismical vessel. It may, therefore, be applied to all bodies in motion which are deeply immersed in any fluid.

By a process, which is too long to be inserted here, it is demonstrated *, that the resistance which a fluid makes to a cylinder moving in it in the direction of its axis, is equal to the weight of a column of the fluid, whose base is equal to that of the cylinder, and height is equal to half the space through which a body ought to fall in vacuo to acquire the velocity with which the cylinder moves.

Hence the resistance and retardation of a body moving in any fluid may be found, if

ception of parallel rays, and which falls on a plane surface situate at right angles to the direction of the rays, is the orthographic projection of the outline of that body.

* Princip. 37. l. 2.

the velocity of its motion, its bulk and weight, together with the density of the fluid be known. An instance will render this familiar.

Suppose a globe of lead of three inches diameter, and 84 oz. troy weight to be moved in water, with a velocity of 2 feet in a second; it is required to find the resistance and retardation which the water makes to its motion?

A falling body, as has already been observed, describes the space of $15\frac{1}{2}$ Paris feet in a second of time; which is equal to $16\frac{1}{16}$ English feet. But for the sake of round numbers, let us call it 16 feet. And the last velocity of an equably accelerated motion, is such as would, uniformly in the same time, describe twice the space already described *ab initio*. Now, the spaces described are as the squares of the velocities; therefore,

As the square of the velocity of			
32 feet per second,	-	-	1024
Is to the space by falling which			
that velocity was acquired,	-		16
So is the square of 2, the given			
velocity,	-	-	4

To

To the space by falling which

it would be acquired - - $\frac{6\frac{1}{2}}{1024}$ or $\frac{1}{16}$.

The half of which, or $\frac{1}{32}$ of a foot, is the length of the column of water; and its diameter being three inches, it will weigh $2\frac{1}{2}$ oz. troy, which therefore shews the quantity of the resistance.

The resistance being thus discovered, we may consider the effect in the same manner as if a body of 84 oz. had struck with a velocity 2 against a quiescent body of $2\frac{1}{2}$ oz. and easily discover the velocity of the body 84 after the stroke, and consequently find its retardation.

For the motion of the first body before the stroke is expressed by 84 multiplied by 2, or 168; and the whole sum of the motion is not altered by the mutual action of the bodies. Therefore, after the stroke, the quantity of motion continues to be 168, though the mass is increased by the addition of $2\frac{1}{2}$, by that means becoming $86\frac{1}{2}$ instead of 84. To find the velocity, divide the quantity of motion, 168, by the mass, $86\frac{1}{2}$, which gives $1\frac{2}{17}$, the difference between which and the former velocity 2 is the retardation, that is to say, $\frac{1}{16}$.

Thus it appears, that in order to maintain the uniform motion of a body in a fluid, a constant accession of force is required to overcome the resistance; but as, in general, there is no such accession in the motions which are performed about us, they all decay by degrees, and at length terminate.

It likewise appears, that when a body moves in any fluid, and is acted upon by any constant force, it can obtain but a certain degree of velocity. For, as the resistance increases with the velocity, but in a higher proportion, namely, as the squares, it is plain that the resistance at a certain period of the acceleration, will become equal to the constantly acting force; after which the body will proceed uniformly, and the constantly acting force will be employed in overcoming the resistance: On this account it is, that bodies which sink in water, or other fluids, by the force of gravity, do soon acquire their utmost velocity, and afterwards proceed uniformly. And, in like manner, a ship, when it first gets under way, proceeds with an accelerated velocity, till the resistance of the water becomes in equilibrio with the action of the
wind

wind on its sails, after which it proceeds uniformly, the force of the wind being entirely employed in overcoming that resistance.

In mathematical strictness it is not true, that a body in these circumstances ever arrives at uniformity of motion; for the approach of the resistance to an equality with the impelling force is represented by a converging series, the number of whose terms is infinite: but the latter terms soon become too small to be of any physical consequence.

What is here said of resistances is to be understood of bodies deeply immersed in fluids, the parts of which are compressed together, and non-elastic or incapable of condensation. Friction is likewise neglected. Bodies which move at or near the surfaces of fluids, more especially if they be obtuse, cause the fluid to rise into a heap before the body, at the same time that it subsides at the hinder part. In like manner, obtuse bodies, moving in elastic fluids, condense that part of the fluid towards which they are moving, while the part from which they recede is rarefied. In these cases the resistances are greater than appears by the principles just treated of.

B O O K II.

S E C T. IV.

Of the Air.

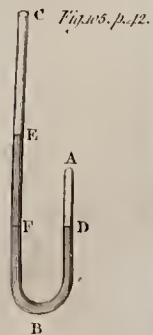
C H A P. I.

*Of the general Properties of the Air ; and of
the Dimensions of the Atmosphere.*

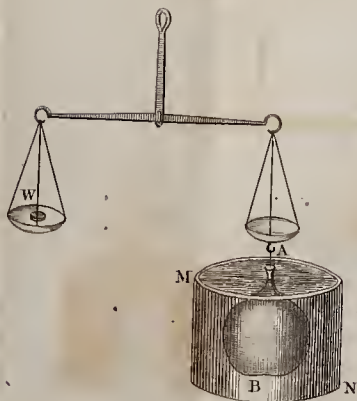
CONTINUAL experience evinces, that we are surrounded by, and immersed in, a fluid, which agitates bodies when it is in motion, which resists the motions made in it, which sustains bodies floating in it, and, in short, which differs from the grosser fluids, in few respects, except those of transparency, elasticity, and gravity ; the two first of which properties it has in a greater,



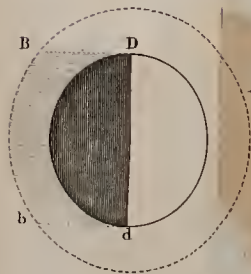
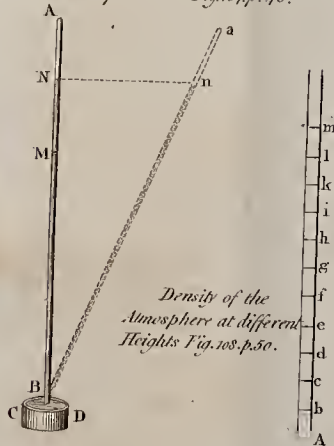
Elasticity of the Air.



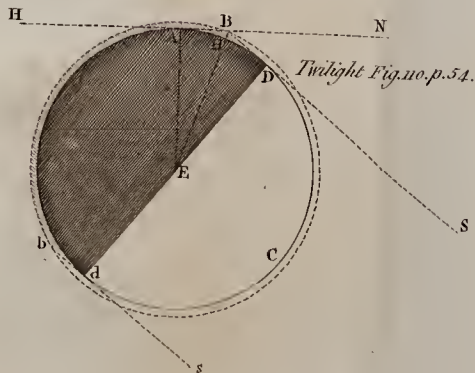
Weight of the Air Fig. 106. p. 44.



Torrillian Experiment Fig. 107. p. 15.



*Twilight
Fig. 109. p. 54.*



greater, and the latter in a less degree than other fluids.

The whole mass of this fluid, with its contents, is called the atmosphere; which term is made use of when we consider the effects which arise from its form, magnitude, density, &c. but when we speak indefinitely of the fluid of which the mass is composed, with a view to develop its qualities, and consider it independant of the bodies which are immersed in, or mixed with it, it is called the air, or air.

The philosophers of antiquity classed the air among the elements or principles which enter into the composition of bodies, and the doctrine was long received by the moderns. At this day there are many who consider pure air, that is, air which is not mixed with moisture or the effluvia of bodies, as an uncompounded fluid; by which we must understand a fluid whose particles are uniformly similar, and indestructible. For, if they be not uniformly similar, it may be decomposed by the separation of the particles of any one sort; and if the particles be not indestructible, it may not only be decomposed,

ed, but its properties entirely changed, by their comminution. Experiment does not confirm this opinion, for it is proved capable of decomposition. But this is not our immediate purpose. It will be more regular to advert, in the first place, to the more obvious properties of the air, and afterwards enquire what it is that enters into its composition.

Air then is a fluid, whose particles are not in contact, and repel each other, which repulsion may be diminished, but cannot be destroyed by any degree of cold that is known in the vicinity of the earth. For, if the particles were in contact the fluid could not be compressed, and if they did not repel each other, the fluid could not expand when the compressing force is removed: but this elasticity is the property of the air, as may be shewn by various methods; one of the simplest of which is, to pour a quantity of quicksilver in the tube ABC (fig. 105.) which is closed at A, and open at C. Suppose the tube to be filled with quicksilver to E, then the air inclosed in the leg AB will prevent its rising higher than D. Mark F in the same horizontal

zontal

zontal line with D, and by what has before been said concerning hydrostatics, the column DB will be in equilibrio with FB, and consequently the quicksilver contained between F and D will not at all press on the air between A and D. But the column EF acting with its whole weight on the quicksilver between F and D causes it to press on the air at D, and condense it. By increasing the quantity of quicksilver the condensation is increased, and it is found, that the spaces into which the air is condensed by different weights are inversely as those weights.

The latter part of the definition is that which distinguishes air from vapor, which is a fluid, the repulsion of whose particles may be destroyed by cold, and the whole condensed into a gross fluid by their coalition. Perhaps the difference between air and vapor may, in this particular, be much the same as between quicksilver and melted metal, lead, for instance; the former of which requires the most intense cold to reduce it to a solid form, while the latter is not exhibited in a fluid state without the application of a very great degree of heat.

One of the first objects of enquiry that offer themselves on this subject is the extent or magnitude of the atmosphere. Experience assures us, that it is extended over the whole surface of the earth and sea ; and it is evident, from the suspension and motion of the clouds, that its altitude is considerable ; but the measure of this altitude must be obtained from its effects. Thus, if the specific gravity of the air be found, and also its whole pressure on bodies, it will be easy to discover the quantity and the height of the fluid. Another method of discovering the height of the atmosphere is deduced from optical considerations, by observing the effect it has on the light of the Sun. We shall speak of both in their order.

Let AB (fig. 106.) represent a bottle, whose contents are exactly known ; for example, suppose it capable of holding two pounds of rain-water ; let a valve, opening outwards, be fitted at A, and the air be exhausted from within by means of the air-pump, hereafter to be described ; let the vessel thus exhausted be weighed in * water, or any other dense fluid,

* The intention of which is, that the scales being loaded as little as possible, may the more readily turn

in the vessel MN, as represented in the figure, after which let the air be admitted. An additional weight of about $14\frac{1}{2}$ grains will be required to restore the equilibrium: therefore, the air contained in the vessel AB weighs $14\frac{1}{2}$ grains, the proportion of which to two pounds is 1 to 800, or $1\frac{1}{4}$ to 1000.

The specific gravity of air being thus discovered, its pressure may be found by the Torricellian experiment, so called from its inventor Torricellius. Let AB (fig. 107.) represent a glass tube of the length of 35 inches or upwards, closed at the end A, and open at B; fill the same with quicksilver, and close the orifice at B with the finger, or otherwise: immerse the end B in the vessel of quicksilver CD, and remove the finger from the orifice; then the quicksilver will subside to N in the tube at the height of about 30 inches.

In the infancy of the modern philosophy, the solution of the cause of this phenomenon afforded matter for great controversies; at present, the gravity of the atmosphere being

with the least alteration of weight; for the less they are loaded, the less is the friction at the fulcrum.

no longer in doubt with any that have at all attended to physiological subjects, it is readily explained on the common principles of hydrostatics: for which purpose it must be remembered, that the pressure, which a body, immersed in the vessel CD, would sustain, is not only that which arises from the weight of the quicksilver, but likewise from that of a column of the atmosphere, which is incumbent on its surface; so that every column of the quicksilver presses with a force that exceeds its own weight. When the tube is inverted into the vessel of quicksilver, the surface of the column which it contains being defended from the pressure of the atmosphere, by the closure at A, can press downwards with no more than its own weight; and will, therefore, be in equilibrio with the pressure which the quicksilver in the vessel exerts against its descent, then only, when it is so much longer, that the additional quicksilver may be equal to the additional weight which a similar column in the vessel receives from the pressure of the atmosphere; that is to say, the pressure of the atmosphere on any given surface is equal to the weight of a column of mercury,

mercury, whose base is the given surface, and height equal to that at which it stands in the Torricellian tube; and this pressure is the weight of a column of air, whose base is the given surface, and height equal to that of the atmosphere.

It has been shewn, that when the air is condensed, its density is in the reciprocal proportion to the weight that compresses it. By means of the Torricellian tube we may observe, that the same ratio obtains when it is rarefied by taking off part of the weight of the superincumbent atmosphere. For, in any elastic fluid at rest, the spring must equal the compressing force; and if any part of that force be taken away, it must expand till the spring becomes equal to the remainder; which will happen if the elasticity of the fluid be weakened by expansion. And since the pressures of fluids are as their heights, the pressure of the Mercury in the tube aB will be equal to that in the tube AB , when the mercury rests at n in the same horizontal line with N . Now, if a bubble or small quantity of air be admitted into the tube AB , it will depress the mercury below the mark N

I

till

till its spring and the weight of the mercury remaining in the tube be in equilibrio with the pressure of the atmosphere; that is, if the mercury be depressed to M, that part of the weight of the atmosphere which corresponds with the quantity of mercury MB, will be sustained by the weight of the mercury, and the remainder MN will be sustained by the spring of the included air. The included air then, being pressed by a weight less than that of the whole atmosphere, becomes rarefied or expanded. By variously inclining the tube the included air may be made to bear more or less of the weight of the atmosphere, (as may be gathered by measuring the perpendicular altitude of M above the surface of the quicksilver contained in the vessel CD, and subtracting it from the altitude BN, which corresponds with the weight of the whole atmosphere) and its contraction or dilatation observed: whence it appears, that the air, though greatly rarefied, occupies a space which is reciprocally proportional to the compressing force.

If two columns of uniform fluids, whose specific gravities differ, be equal in weight,
and

and stand on equal bases, their heights will be reciprocally as their specific gravities. The specific gravities of quicksilver and air are respectively 14019 and $1\frac{1}{4}$: therefore,

As the specific gravity

of air, - - - - - $1\frac{1}{4}$

Is to the specific gra-

vity of mercury, - 14019

So is the height of the

column of mercury, - 30 inches

To the height of an

equal column of air 336456 or $5\frac{1}{4}$ English miles.

This would be the height of the atmosphere, if it were uniformly of the same density; but as that is not the case, on account of the elasticity which causes the upper parts to expand in proportion as the weight of the superincumbent parts becomes less, as was before observed, the altitude must be much greater.

The density of the air in that part of the atmosphere in which we live being shewn to be, in all cases, as the weight that compresses it, it is plain, if the constitution of the air in the superior regions be of the same kind, that its density at any altitude will be as the weight

or quantity of the superincumbent air. Suppose Am (fig. 108.) to be a column of the atmosphere, and imagine the same to be continued at pleasure beyond m, so as to reach its utmost limits. Let this column be divided into an indefinitely great number of equal parts, Ab, bc, cd, &c. and the quantity of air contained in any one of those parts, or its density, will be in proportion to the quantity of air which is superincumbent on that part. Now, the difference between the quantities of air incumbent on any two contiguous parts is the quantity contained in the uppermost of those parts; that is, for example, the quantity superincumbent on d is less than that which is incumbent on c by the difference or part cd: therefore the quantities contained in the equal parts or divisions are the differences between the incumbent masses of air taken in a regular succession. And these quantities or differences have been shewn to be in proportion to the incumbent masses. * Now,

* Let a, b, c, d , &c. be magnitudes whose differences are as the magnitudes themselves. -

That is $a - b : b :: b - c : c :: c - d : d$, &c.
 Whence $a c = b b, b d = c c$, &c.
 Consequently $a : b : c : d$, &c.

it is demonstrable, that if any succession or series of magnitudes do increase or decrease in such a manner, that the differences shall be in proportion to the magnitudes themselves, then those magnitudes, and consequently their differences, shall be in a continued geometrical progression: whence it follows, that the densities or quantities of air contained in the equal divisions or parts *Ab, bc, cd, &c.* do decrease in a continued geometrical progression.

[illegible]

This reasoning depends on the supposition that the superior air is of the same constitution as that in which we live ; but it must be confessed, that by the experiments which have been made on the air at the top of mountains, the pressure seems to decrease in a higher proportion ; so that the air in the upper regions must be more elastic than that near the surface of the earth, whose spring may perhaps be diminished by various exhalations. To discover the circumstances on which this difference of constitution depends, is an enquiry that well deserves attention ; and when the subject shall be farther elucidated, it is probable that the above ratios may, notwithstanding, be applied with advantage.

Much pains have been taken to discover the causes which influence the altitudes of the mercury in the Torricellian tube at different heights above the surface of the earth. If this could be accurately done, it is plain that we should have an easy method of measuring the heights of mountains, and other elevations. For the heights of the mercury being known, would indicate the correspondent altitudes of the eminences on which the
tube

tube was placed. And notwithstanding all the difficulties which occur in the practice, this method of measuring heights is little inferior, if not even equal, to any other.

The other method of discovering the height of the atmosphere is deduced from observations of the morning and evening twilight. Notwithstanding the very great transparency of the air, it may be rendered visible by means of the rays of light, which are incident on its particles, and thence reflected in all directions. This is evident from the appearance of the beams of the Sun admitted into a room through the window-shutter, and may frequently be observed when the Sun shines through the chasms or openings in a dark cloud: whence it happens, that those bodies which emit a very small quantity of light are not to be discerned in this stronger light. In the day-time the stars are invisible, and the flame of a candle can scarcely be seen in the sun-shine: were it not for this illumination the sky would appear black, and the shady sides of objects would be of a dark colour, almost the same as at midnight.

The Sun shining on the globe of the earth can illuminate but one hemisphere at once, as has already been shewn; but it is not so with the atmosphere which environs the globe. Thus, the illuminated part of the globe terminates at D and d (fig. 109.) but the atmosphere is enlightened as far as B and b. In consequence of which it happens, that those parts which have already entered into the dark hemisphere, and to whom therefore the Sun is set, do still enjoy a degree of light which continues as long as any of the enlightened part of the atmosphere remains in view. This light, which gradually decays after sun-set, or increases before sun-rise, is called the twilight. Let AHDCdb (fig. 110.) represent a section of the earth in the plane of the Sun's azimuth, and let the space contained between the concentric circles represent the atmosphere: then, the Sun's rays in the directions SB, sb, will illuminate half the globe DCd, and the atmosphere will be enlightened as far as B and b on each side within the dark hemisphere; which enlightened part, so long as it continues above the horizon of any place, will cause a twilight at that place.

place. The ray SDB is a tangent to the Earth at D, and meets the circumference of the atmosphere at B. From B draw the line BH, a tangent to the Earth at A, which continue towards N; H N will then represent the horizon, in which the extreme point B of the enlightened part of the atmosphere will be situated; that is, twilight will be just beginning or ending at the place A. The angle SBN, which is equal to the angle AED, will be the angle of the Sun's depression beneath the horizon HN; and the angle AEB is the half of AED. Hence, if the depression of the Sun beneath the horizon, and the semidiameter of the Earth be known, it will be easy to find the height of the atmosphere. For, in the right angled triangle ABE,

As the sine complement of

half the Sun's depression AEB $8^{\circ} 30'$

Is to the Earth's semidia-

meter - - - AE 3437 miles,

So is radius - sine 90°

To the hypotenuse - EB 3475 miles.

The difference between which and the semidiameter of the Earth is the line HB or height of the atmosphere, 38 geographical, or 44

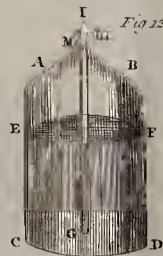
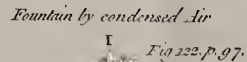
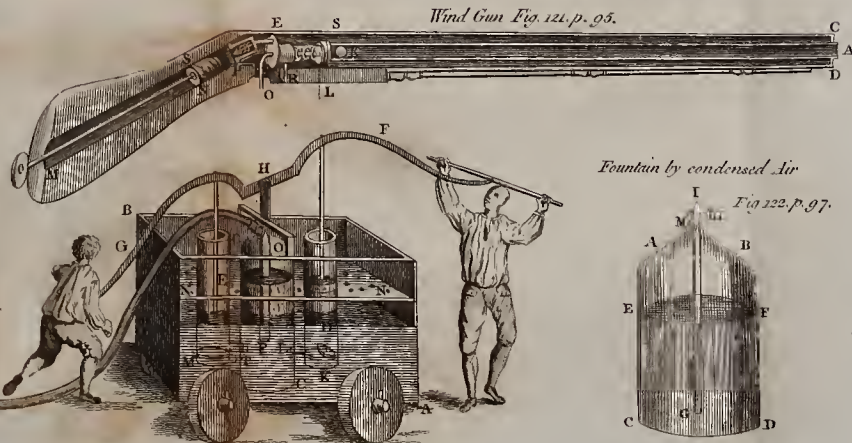
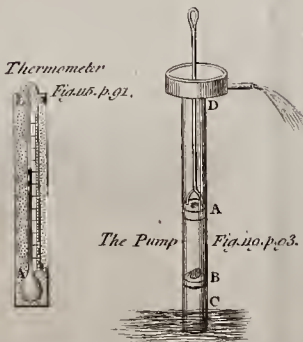
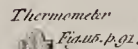
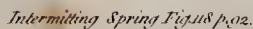
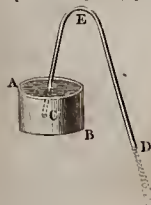
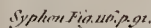
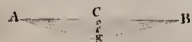
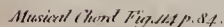
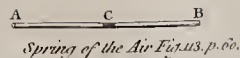
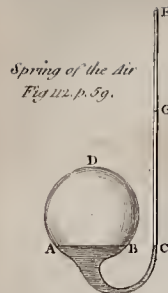
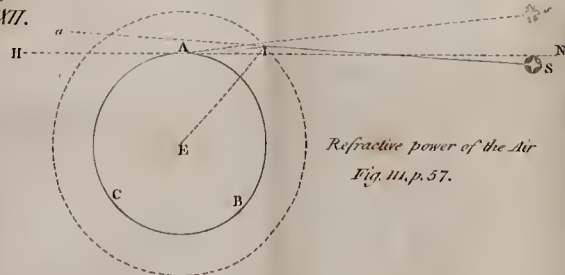
English miles. The angle of the Sun's depression is known by the time elapsed between the beginning or end of twilight, and the rising or setting of the Sun; and it is judged to be twilight so long as the illumination of the atmosphere prevents the smaller fixed stars from appearing. It is also observed, that the evening are always longer than the morning twilights, which must arise from the rarefaction of the air over the place, after the day's sun-shine. A similar difference is observed between the twilights of summer and winter.

C H A P. II.

Of the refractive Power of the Air; and of its Rarefaction and Condensation by Heat and Cold.

THAT the celestial space or heavens is either nearly or absolutely vacuous, appears from the small resistance the planetary bodies suffer in their motions; such resistance, if it obtain at all, being too minute to be observed by any of the methods yet invented. Light therefore, when incident





dent on our atmosphere, passes from a rarer to a denser medium, and ought, according to the principles of optics, to be refracted towards the perpendicular. And this is accordingly the case. Let the circle ABC (fig. III.) represent a section of the Earth, and the external concentric circle the surface of the atmosphere; let HN be the sensible horizon of a place A, and S the Sun beneath the horizon; then a ray of light incident on the surface of the atmosphere at I, will, instead of proceeding to a, be refracted towards the perpendicular IE, and that continually the more as the density of the medium becomes greater, so that it will arrive at A after passing through the curve IA; and a spectator at A will behold the Sun in the line of the last direction of the ray, namely in that of As, the tangent to the curve. The apparent elevation which a celestial body suffers when its rays fall with the greatest obliquity, to wit, when it is seen in the horizon, is about thirty-three minutes of a degree: at other altitudes the differences between the true and apparent places are less, the incidences and refractions being less considerable.

Hence

Hence it comes to pass, that we see the celestial bodies for some time after they are set, and before they rise, in reality, by which means we enjoy about three days in the year more day-light than otherwise we should: but in the northern parts, where the sun rises and sets more obliquely, and the atmosphere being condensed by cold, refracts more strongly, the difference is much greater.

The refraction, as well as all the other phenomena produced by the atmosphere, are variable, as the density of the air changes. This variation renders the observation of low altitudes very uncertain, as the allowance for refraction cannot be collected with precision from any tables. On this account also, the trigonometrical admeasurement of the heights of lofty mountains cannot be depended on to any degree of correctness.

It has been occasionally remarked, that the air is condensable by cold; but cold, as far as its properties are yet known, appears to be no more than the absence or privation of heat, therefore the expression will perhaps be more accurate, if we say that heat rarefies the air, or increases its elasticity, and as a consequence

quence or converse of the assertion say, that cold, or the privation of heat, suffers it to condense, or condenses it, not by a positive action, but by the negation of the act of rarefying. But these distinctions in expression are of no great importance, provided we do not pervert the sense, and take words for things, as is too often the case in philosophical, as well as other researches. The increased spring of the air by heat is proved by the following experiment.

Let ADB (fig. 112.) represent a hollow glass ball, to which is affixed the narrow bent tube ACGE. The lower part of the bent tube and part of the ball is filled with mercury, as in the figure, the surface AB within the ball being on the same horizontal line with the surface at C in the tube. The parts of the mercury will then be in equilibrio, the external surface C being pressed by the weight of the atmosphere, and the internal surface AB being pressed by the spring of the included air, which is equal to that weight. But if the ball be immersed in boiling water, the increased spring of the included air pressing on the surface AB, will raise the mercury

1

cury from C to G, and there sustain it, namely, at the height of $8\frac{4}{7}$ inches, when the mercury in the Torricellian tube stands at 30 inches. And as the contained air is not sensibly dilated by the extrusion of so small a quantity of mercury, the sustentation may be regarded as the entire effect of its spring. The spring of the included air at the heat of boiling water is therefore not only equal to the weight of the atmosphere, but likewise to an additional pressure of more than $\frac{1}{30}$ of that weight.

By the same instrument, it is found, that the air is contracted in its dimensions by immersion in very cold or freezing mixtures. And conclusions similar to these may be made by various methods, which the attentive learner will readily discover.

In the foregoing experiment the air was prevented from expanding, in consequence of its increased spring, by the pressure of the mercury, but if the tube AB (fig. 113.) which is closed at B, and open at A, a small quantity of mercury C being admitted, which incloses the air between C and B, be immersed in boiling water, the included air CB is found

by the motion of the mercury at C to be expanded in the proportion of 3 to 2 beyond its bulk at freezing cold. By this means it is found, that the greatest difference of the expansions of the air in summer heat, and the cold of the air when water is beginning to freeze, is as those of the numbers 7 and 6. In these experiments, if there be any moisture in the included air, a much greater degree of dilatation follows; for the expansion of vapours by heat is much more considerable than that of the air itself.

It will be easy from the above, to indicate the causes of many phenomena that happen in the air. For, if any part of the air be heated, it will expand, and in consequence of that expansion, become specifically lighter than before. It must, therefore, by the laws of hydrostatics, ascend, and the circumambient air must press in on all sides to supply its place. Hence the cause of the ascent of smoke in a chimney. The air which passes through the fire, or comes within a certain distance from it, is rarefied, and ascends, giving place to the cold air which presses in: this in its turn becomes rarefied, and the ascending

ascending current of air continues as long as the fire is kept up, the wind drawing from all parts towards the chimney, as experience testifies.

If the fire were in the open air, the heated air would still ascend in a current, and the cooler air press in on all sides; that is to say, a wind would be generated, which would constantly blow towards the fire. The quantity of air, which is rarefied by any fire we can make, is so small, that the wind produced by that means is too inconsiderable to be perceived at any great distance from the fire; but the rarefactions which arise from natural causes are sufficient to produce all the winds with which the atmosphere is agitated.

C H A P. III.

Of Winds, and their Causes.

BEFORE we proceed to describe and account for the winds which are observed in the atmosphere, it will be necessary to premise, that the sensible horizon is not only divided into 360 degrees, like other great circles, but also into 32 equal parts, which are called points of the compass, which points are again subdivided into halves and quarters. The points of the compass have each a separate name. Those points in which the meridian intersects the horizon, are termed North and South; and two other points, at the distance of 90° from the North and South, are termed East and West: these four are denominated cardinal points. The intermediate points take their names from the cardinal points between which they are situated as in the figure, where the initial letters N. S. E. W. (fig. 117.) stand for the words North, South, East, West.

A wind

A wind is named from the point of the compass from which it blows.

The different winds may, with respect to their direction, be reduced into three classes; viz. general, periodical, and variable winds.

General winds are those which blow always nearly in the same direction. In the open seas, that is, in the Atlantic and Pacific Oceans, under the equator, the wind is found to blow almost constantly from the eastward; this wind prevails on both sides of the equator to the latitude of 28° . To the northward of the equator, the wind is between the North and East, and the more northerly the nearer the northern limit; to the southward of the equator, the wind is between the South and East, and the more southerly, the nearer the southern limit.

Between the parallels of 28 and 40 south latitude, in that tract which extends from 30° West to 100° East longitude from the meridian of London, the wind is variable, but by far the greater part between the N. W. and S. W. so that the outward bound East
India

India ships generally run down their easting on the parallel of 36° south.

Beyond the northern limit of the general wind in the Atlantic Ocean, the westerly winds prevail, but not with any certainty of continuance.

Near the western coast of Africa, within the limits of the general wind, the winds are found to be deflected towards the shore, in-
somuch that they are found to blow from the N. W. and S. W. quarters for the most part, instead of the N. E. and S. E. as is the case farther out at sea.

The general winds are usually called trade-winds.

In the Atlantic Ocean, the S. E. trade-wind extends as far as 3° north, and the N. E. trade-wind ceases at the 5th degree N. In the intermediate space are found calms with rain and irregular uncertain squalls, attended with thunder and lightning. But this space is removed somewhat farther to the northward or southward, according as the Sun's declination is more northerly or southerly.

Periodical winds are those which blow in a certain direction for a time, and at stated

seasons do change and blow for an equal space of time from the opposite point of the compass. These may be divided into two classes; viz. monsoons, or winds that change annually; and land and sea breezes, or winds that change diurnally.

While the Sun is to the northward of the equinoctial, that is to say, in the months of April, May, June, July, August, and September, the wind blows from the southward over the whole extent of the Indian Ocean; namely, between the parallels of 28° N. and 28° S. latitude, and between the eastern coast of Africa, and the meridian which passes through the western part of Japan. In the sea between Madagascar and New Holland, the S. E. wind prevails as far as the equator, where it deflects and blows into the Arabian Gulf and Bay of Bengal from the S. W. Between Madagascar and the main land of Africa, a S. S. W. wind obtains and coincides with the S. W. winds in the Arabian Gulf. To the northward of New Holland, the S. E. wind is predominant, but varies very much among the islands; and between the peninsula of Malacca and the Island of Japan, a S. S. W. wind

W. wind prevails. All this is to be understood for the aforementioned months.

But in the other months, October, November, December, January, February, and March, a remarkable alteration takes place. In the sea between Madagascar and New Holland, the S. E. wind extends no farther to the northward than about the 10th degree of south latitude, the other 10 degrees being occupied by a wind from the opposite point of the compass, or N. W. at the same time that the winds in all the northern parts of the Indian Ocean shift round, and blow directly contrary to the course they held in the former six months. These winds are called monsoons, or shifting trade-winds.

These changes are not suddenly made. Some days before and after the change, there are calms, variable winds, and dreadful storms, attended with thunder, lightning, and rain.

On the greater part of the coasts of lands situated between the tropics, the wind blows towards the shore in the day-time, and towards the sea in the night. These periodical winds are termed the land and sea breezes, and are much affected, both in their

direction and return by the courses of rivers, tides, &c.

Variable winds are those which are subjected to no period, either in duration or return, and are too well known to need description.

In our attempts to explain those appearances, it will be necessary to consider what may be the causes of wind in general, and afterwards, as far as observation enables us, to apply the result to the solution of particular cases.

If the air were uniformly of the same density at the same height, and the lighter parts always reposed upon the heavier, it is evident that, the lateral pressure being equal in every horizontal direction, it would remain at rest. But, on the contrary, if any portion or part of the air were heavier than the rest, it would descend, or if lighter, ascend, till the equilibrium was restored; and, in the first case, the air displaced would occasion a wind, diverging as it were from a central space, and in the latter, the air rushing in, would occasion an appearance quite contrary, namely, a wind converging to a central space. Hence it appears,
that

that any agent that alters the density of a part of the air, will produce a wind.

Experience has shewn no more than two methods by which the density of the air may be altered, namely, the application of compression, or of heat. The compression which the air suffers in the natural course of things, is at all times nearly uniform and the same, and consequently can produce no motion in the atmosphere. It remains, therefore, to be considered, in what manner the air is affected by the heat which it suffers at different times and seasons.

If the Earth did not revolve on its axis, it is plain, that the Sun, being stationary over one particular spot, would rarefy the air at that spot: it would consequently ascend by the pressure of the circumambient and less rarefied air, till it arrived at a region in which the air was sufficiently rare to suffer it to expand on all sides: and thus there would be produced a converging wind near the surface of the Earth, and a contrary or divergent wind in the upper region of the air. But since the Earth does revolve on its axis, and the Sun therefore is not stationary,

it follows, that the place at which the air is most rarefied will be found successively in every point of the parallel over which the Sun moves in the course of a day. And as this place continually moves to the westward, the lower air must as constantly follow it. Hence we have the origin of the general N. E. and S. E. trade-winds, which no doubt would extend over the whole of the space between the tropics, were it not for the different temperatures of the continents and islands over which the Sun passes. For the surface of earth is more heated than that of the sea, by reason that the transparency of the water permits many of the rays of light to pass to its interior parts before they are stifled and lost. The air therefore, which is contiguous to the land, being more heated than that which rests upon the sea, will prevent the regularity of the effect. Thus, near the western coasts of Africa and America, the winds blow from the westward, to supply the constant rarefaction which those heated lands produce.

The general N. E. and S. E. trade-winds, producing in the upper region of the air winds in the contrary directions, seem to be the cause of the westerly winds which are observed to prevail between the latitudes of 28° and 40° .

In accounting for the monsoons, or periodical trade-winds, it is necessary to mark the peculiar circumstances which obtain in the Indian Ocean, and which are not found in the Atlantic or Pacific Oceans. They seem to be these. That the ocean is bounded to the northward by shores, whose latitude does not exceed the limits of the general trade-wind, and that the general trade-wind falls on lee-shores to the westward.

The Sun being twice in the year vertical in the equator, and never departing more than $23\frac{1}{2}^{\circ}$ from thence, causes the air in that climate to be hotter than at any other place on the ocean; and is the occasion of the trade-wind, as has already been shewn. Such a rarefied space must extend across the Indian Ocean, and produce a S. E. wind to the southward, and a N. E. wind to the northward of the equator, over which, in the upper

regions of the air, the winds return in the contrary directions. This we accordingly see happens in the months of October, November, December, January, February, and March. But when the Sun declines to the northward, and heats the lands there situate, the air contiguous to those lands becomes rarefied, and the lower air has a tendency to move that way. This tendency increases as the Sun advances farther North, insomuch that the whole body of the lower air to the northward of the equator moves thither, notwithstanding the equatorial rarefaction, which must be supplied by the upper or returning current. So, that the body of the lower air in the northern part of the Indian Ocean is determined as to its course by the greater rarefaction: if the rarefaction at the surface of the land be greater than that at the equator, the wind blows to the North, and the contrary happens when the equatorial rarefaction is greatest. When the northerly trade-wind prevails, it blows out of the Arabian Gulf upon the coasts of Arabia, Aynan and Zanguebar, and is reflected into the straits of Mosambique. And at the other season, the
general

general southerly wind seems to be reflected to the westward by the same cause.

These, or some such like, are probably the causes of the winds which prevail in the Indian seas. But the observations we are in possession of are too few and too inaccurate for the purpose of forming a theory. To which may be added, that all the atmospheric appearances seem to depend on so many, till of late unregarded causes, particularly the operation of electricity, that to investigate them more minutely would require a separate volume.

After what has been said, it will not be difficult to account for the land and sea breezes. For the land being heated in the day-time, the wind blows in shore to supply the place of the ascendent rarefied air: and in the night the land cools, and condenses the air, occasioning the land breeze.

The circumstances on which the variable winds depend, are referable to those already noticed, but act so differently in particular cases, that our limits do not admit of an attempt to reduce them to rule.

When

When several winds converge swiftly to one point, the air ascends with great rapidity, and acquires a whirling motion, like that of water descending in a funnel. And as the centrifugal force in this whirling motion of the water is often sufficient to counterpoise the lateral pressure, and to prevent its approaching the central part, it frequently happens, that a perforation is seen quite through the body of the fluid. In like manner, the centrifugal force of the air may become equal to the pressure of the atmosphere, and consequently leave a void space about the center of the motion. This phenomenon is called a whirlwind, and sometimes produces fatal effects. For, partly by the expansion of the air included in houses or other buildings, and partly by the violence of the ascending current, it happens, that bodies near the center of the whirl are blown up into the vacuum, or carried aloft with great impetuosity in a spiral motion.

If one of these whirlwinds happen at sea, the pressure of the atmosphere being taken off that part of the surface over which the vacuum

cuum is formed, the water, on the principle of the Torricellian tube, will rise to the height of thirty-two or thirty-three feet before it will be in equilibrio with the external pressure. The ascending warm air being most probably charged with vapours, will suffer them to be condensed as it arrives in a colder region, and thus the course of the current will be marked by the dense and opaque vapor, and by the continual ascent a cloud will be formed above. These are the phenomena of water-spouts. At first a violent circular motion of the sea is observed for a space sometimes of twenty feet diameter; after which the sea rises by degrees into a solid tapering column of about thirty feet in height, at the same time that a cloud appears, from which a dark line or column descends. This column is met by another, which ascends somewhat like smoke in a chimney, from the lower or solid part of the spout. After this junction the cloud continually increases till the whirl ceases, and the appearance terminates.

But though water-spouts undoubtedly depend in a great measure on the convergence and circular motion of winds; yet, as we
have

have already had occasion to remark concerning the trade-winds, it is probable that other unheeded causes concur in producing the appearance.

C H A P. IV.

Of Sound; and of Music.

IN speaking of the resistances which bodies suffer when moving in fluids, we observed that obtuse bodies moving in elastic fluids condense that part towards which they move at the same time that the part from which they recede is rarefied. This condensation or rarefaction must produce an undulatory or vibrating motion in the fluid. Thus, if a body by percussion or otherwise be put into a tremulous motion, every vibration of the body will excite a wave in the air, which will proceed every way in a circular motion, and the quicker the vibrations of the body succeed each other, the less will be the distance between each successive wave. It is also * demonstrated, that the velocity with

* Princip. 47. l. 2.

which a wave moves from the tremulous body in an elastic fluid, whose density is in proportion to its compression, is uniform and the same, whether the interval between the waves in succession be less or greater.

The sensation which is excited in the mind by means of these waves which enter the ear, and produce a like motion in a thin membrane, that is stretched obliquely across the auditory passage, is called sound. But in vulgar language the term is used to imply not only the sensation excited in the mind, but likewise the affection of the air, or of the sonorous body by which that sensation is produced. Thus, we say, that a sound is in the air, or that a body sounds when struck, though the affection of the air or body is very different from the sensation. We have several times had occasion, in defining the philosophical uses of terms, to observe the imperfections of common speech. Precision and accuracy render it necessary. When, therefore, we say, a body sounds, it must be understood that the body or its parts vibrate so as to occasion waves in the air; when we say a sound flies or passes in the air, it must be understood that
a system

a system of waves, produced by a like number of vibrations in a sonorous body, proceed every way in circles from that body; and when we speak of sound abstractedly, we must be understood to mean, that these two acts taking place do, by means of the ear, occasion an idea or sensation in the mind.

That sonorous bodies do move or tremble, scarce needs any illustration: it is evident in drums, bells, and the like, whose vibrations being large and strong, are therefore more perceptible: and that a similar vibration is excited in the air, is plain from the motions produced in bodies that are adapted to vibrate in coincidence with the sonorous body.

Since the waves, in all cases, move with an uniform and equal velocity, it follows that all sounds, loud or low, acute or grave, must arrive at the ear in equal times from sonorous bodies equally distant. This is confirmed by experience; for all sounds are found to move 1142 English feet in a second of time. The knowledge of the velocity of sound is of good use for determining distances of ships, or other objects: for instance, suppose a ship fires a gun, the sound of which is heard 5 seconds after

after the flash is seen; then, 1142 multiplied by 5, gives the distance, 5710 feet, or 1 English mile and 430 feet.

When the waves meet with an obstacle which is hard and of a regular surface, they are reflected, and consequently an ear placed in the course of these reflected waves will perceive a sound similar to the original sound, but which will seem to proceed from a sonorous body, situated in like position and distance behind the plane of reflection as the real sonorous body is before it. This reflected sound is called an echo.

The waves of sound being reflexible nearly the same in effect as the rays of light, may be deflected or magnified by much the same contrivances as are used in optics, though the continual decrease in the force of the waves as they expand, by which sound constantly decays as the distance from the sonorous body increases, makes a considerable difference in the phenomena. From this property of reflection it happens, that sounds uttered in one focus of an elliptical cavity are heard much magnified in the other focus: instances of which are found in several domes and vaults, particularly the whispering gallery, which runs

round the lower part of the circular dome at St. Paul's Cathedral in London, where a whisper uttered at one side is reflected to the other, and may be very distinctly heard. On this principle also is constructed the speaking trumpet, which either is or ought to be a hollow parabolic conoid, having a perforation at the vertex, to which the mouth is to be applied in speaking, or the ear in hearing.

Besides the advantages we enjoy from the existence of sound, in advertising us of danger, and the like, from without, when the sense of seeing ceases to be useful, and in conveying our thoughts to each other by means of the association which we form between words and ideas, there is another benefit which arises from the pleasure we receive, from that combination of sound which is known under the name of music. This pleasure is so great, that in all nations and ages music has formed the chief part of the idea of that bliss which awaits the virtuous in a future state. To those who feel themselves enlivened at the jocund strain, or whose hearts overflow at the plaintive and melancholy note, no proof will be necessary to shew that this delightful science

science can command the affections: and if there be any such as are callous to the impressions of this noblest source of pleasure, the attempt would be vain, for no words can convey an adequate notion of its effects.

In the spring season of the year, when the whole face of Nature puts on the appearance of renewed life and vigour; the birds begin to tune their irregular melody. The mind of man naturally expands with delight at the pleasing scenes about him, of which the animated part attracts the most attention. For this reason he ascribes that pleasure to the music of the feathered race alone, which in reality is the effect of the whole scene. With equal propriety he might ascribe it to the whistling plowman, the lowing ox, or the bleating lamb. Images that contributed perhaps at least an equal share to his pleasure. Hence probably originated the notion, that the invention of music arose from an imitation of the birds, though the vast superiority of the human music is sufficient to overthrow such a position. The birds are musical by nature, and man is much more so by the

same cause. To resolve the effect of an evident natural endowment into imitation, must therefore arise from a desire of systematizing, rather than a wish to develop the truth. As the earliest language must have been simple and unartificial, and refined by degrees, so the earliest music must have been rude and incorrect, consisting rather of a wild, though pleasing, melody, than bearing any great resemblance to the compositions of modern times, which have all the advantage of subsequent observation and improvement. But as these speculations do not so immediately tend to our present purpose, we will advert to those circumstances of sound in which music consists.

If a body be struck, and the vibrations excited be isochronous and simple, the undulations produced in the air must be so likewise, whence there will be produced a simple and uniformly similar sound, except as to loudness or intensity; for, as the vibrations grow less strong, the sound decays; but if the vibrations excited be various and dissimilar, a like variety of dissimilar undulations will be produced

in the air; and the sound must be harsh, as if several sounds were heard together. The first of these sounds is a musical tone, and the latter a noise.

This is evident, because we find that those bodies which are the most uniform in their texture, and by consequence best adapted to vibrate simply and isochronally, do produce the most musical tones; as for example, masses of elastic metal, brass, cast-iron, and the like. And this tone is more strictly musical if the metal be so formed as to vibrate in the simplest manner possible. Thus, a hollow metallic vessel or bell, if it be well formed, and not damaged in the tuning, will give but one uniform musical tone, or at least the tones produced will consist of one predominant or principal one, and several others which have a perfect musical agreement with it: a wire of an uniform thickness, stretched over two hard bridges or fulcrums, will produce the same effect. Brevity obliges us to pass over the various means by which musical tones may be obtained, and to attend only to those which are produced by strings or wires, as being the most simple.

Experience and reason have established the following positions respecting the vibrations of chords or strings.

The forces or weights which are necessary to draw an extended chord AB (fig. 114.) out of its place to the distances Ce, Cf, Cg, are directly proportional to those distances, provided the chord be not too much drawn aside.

Therefore, since the forces with which the chord returns to its first situation, when set at liberty, are always in proportion to the space it has to pass through, the vibrations must all be performed in equal times.

If chords differ only in thickness, the times of their vibrations will be directly as their diameters.

If chords differ only in tension, the times of their vibrations will be inversely as the square roots of the weights by which they are stretched.

If chords differ only in length, the times of their vibrations will be directly as their lengths.

That tone which is produced by a string that vibrates quickly is termed acute or sharp, when compared with the tone of a string that

vibrates slower ; and the tone produced by the latter is called grave or flat, when compared with that of the former.

If two chords be struck, either at the same instant or in immediate succession, the coincidence of sound is pleasing or displeasing according as the two tones produced stand related to each other in gravity or acuteness: if they be so related as to afford pleasure, the coincidence is called a concord, but if not, it is termed a discord.

A set of tones which follow each other, and afford pleasure, is called melody; a set of cotemporary tones, which afford pleasure, is called harmony.

The more frequently the vibrations of two chords do coincide with each other the perfecter the concord will be; thus, two equal strings, equally stretched, will each give the same tone; the vibrations of the one will coincide with those of the other, and the concord will be most perfect: again, two strings, which differ only in length, the one being half the length of the other, will vibrate the one twice while the other vibrates once, the coincidence will be at every second vibration

of the shorter string, and a concord will be produced, but less perfect; if the strings be in length as 2 to 3, the coincidence will be less frequent, namely at the third vibration of the shorter string, and the concord will be still less perfect: and so forth.

On this principle, and by the help of the foregoing ratios, are constructed all stringed instruments; that series of musical tones being selected, which experience has shewn to be best adapted for the purposes of melody and harmony. The series is called the diatonic scale, and its properties, together with the names of the tones, may be seen in the following scheme:

Names.	Lengths.	Perfection.
Unison, or fundamental	$1 : 1$	Most perfect concord.
Second - -	$10 : 9$	Discord.
Third greater	$5 : 4$	Imperfect concord.
Fourth - -	$4 : 3$	Imperfect concord.
Fifth - -	$3 : 2$	Perfect concord.
Sixth greater	$5 : 3$	Imperfect concord.
Seventh greater	$15 : 8$	Discord.
Octave - -	$2 : 1$	Perfect concord.

The above is called the sharp series, in contradistinction to the flat series, or scale in which

which the third, sixth, and seventh are less or flat, being in the ratios of $6 : 5$, $8 : 5$ and $9 : 5$; besides which, in practice there are other intermediate tones used as the second lesser and fourth greater, which are in length as $16 : 15$, and $7 : 5$; all these are found in the construction of instruments; that by their means the performer may place his fundamental, or principal note, on any of the tones at pleasure, and use the other tones which stand in the above relations to it; they being sufficiently near for practice, though not so perfectly accurate as in that series for which the instrument is formed.

The notation of music, and the relations which the different scales bear to each other, together with the rest of the particulars on which the rules for composition and accompaniment depend, require too copious an explanation to be admitted in this place: we therefore dismiss the subject, and proceed to give an account of the instruments whose construction depends on the spring or weight of the air.

C H A P. V.

A Description of various Instruments, whose Effects depend on the Properties of the Air.

THE mercury in the Torricellian tube stands at the height of about thirty inches, by means of the pressure of the air, as has already been observed: we have also seen, in considering the phenomena of winds, that this pressure is not every where alike, nor always the same at any particular place. In consequence of which it happens, that the mercury in the Torricellian tube does not preserve the same invariable altitude: for, when the air at any place is dense, the mercury stands at a greater height than when it becomes lighter: thus the tube becomes an instrument to indicate the varying weight of the atmosphere, and when fixed in a proper frame with graduations to measure the altitude of the mercury, is known by the name of the barometer. The variations are between the altitudes of $27\frac{1}{2}$ and $30\frac{1}{2}$ inches.

The

The instrument described at p. 59. is also used for the same purpose, under the name of the marine barometer, it being useful at sea, where the common barometer is of little service, on account of the ship's motion, which causes the mercury to librate up and down in the tube. But as this barometer is subject to alteration, on account of heat and cold, as well as on account of change in the weight of the air; and as the distinguishing the effects of each is attended with some little trouble, it is not much in use on shore.

There are many contrivances for enlarging the divisions on the barometer, such as inclining the tube, and the like; but they are all subject to inconveniences, on account of friction, which the upright barometer is free from, and are therefore not much in request.

In the second chapter of the present section it was observed, that the air is condensed or rarefied by heat and cold. On this account it was formerly made use of to indicate the varying temperature of the weather in those respects: for the marine barometer is a thermometer, and its variations being occasioned by a twofold cause, it is not with facility
applied

applied to either purpose. The thermometer, or instrument by which the degrees of heat and cold are denoted, is therefore constructed by the use of other fluids, though the air-thermometer is not without its convenience for distinguishing very small differences in heat and cold, which are not shewn by those instruments which are made to suit a more extensive purpose.

The property of being expanded by heat, and contracted by cold, is not peculiar to air. All bodies whatsoever are subject to the same, though not equal, mutations; unless we may except some fluids, as water, &c. which cease to contract when the degree of cold is so great as to freeze them, instead of which they are considerably dilated when in the form of ice: it is probable that this last circumstance arises from the expansion of the fixed air, which lies dormant till extricated by the cold. As the pressure of the atmosphere is not considerable enough to alter the dimensions of dense bodies in any sensible degree, it is plain that their mutations will indicate the effects of heat alone, and consequently they must be
very

very proper for the matter of thermometers : and as these mutations are very small in proportion to the whole bulk, solid bodies must be inconvenient for the purpose, on account of the great length required to make them perceptible : but in fluids, by means of proper vessels, it will be easy to render the least alteration visible ; for if the neck or stem of any glass-vessel be very small in proportion to the contents of the bulb or bottle, the least expansion of the included liquor will occasion a visible rise in the neck. Thus, AB (fig. 115.) represents a glass-tube, whose end A is blown into a ball: this ball, and part of the tube, being filled with quicksilver, the least change of the bulk of the quicksilver, and consequently of the temperature of the circumambient air, or contiguous bodies, is shewn by a rise or fall of the surface in the tube ; the quantity of which is indicated by the scale ab, affixed to the frame of the instrument.

If the bent tube CED (fig. 116.) be filled with water, and the shorter leg EC immersed in the water contained in the vessel AB, the water will all flow out at the aperture D, and the vessel will be emptied. For the pressure
on

on the aperture C is equal to the weight of the atmosphere, and is counteracted by the weight of the column EC, and the pressure on D is the same weight, but counteracted by the column ED. And as ED is longer than EC, the pressure of the atmosphere on D will be less effectual than that on C; consequently the water will flow out at the orifice D, receding from the greater pressure. This instrument is called a syphon, and is sometimes used to draw liquors out of casks that are so placed as not conveniently to be moved.

A very probable account of the cause of intermitting springs may be given on the principle of the syphon. For, let GFC (fig. 118.) represent a cavity or receptacle in the bowels of a mountain, from the bottom of which C, proceeds the irregular cavity or syphon CED: then, if by springs or otherwise the receptacle begin to fill, the water will at the same time rise in the leg CE of the syphon till it has attained the horizontal level HH: after which, it will begin to flow out by means of the leg ED, and will continue to increase in the quantity discharged, as the water rises still higher, till at length the
syphon

syphon will emit a full steam, and by that means empty the receptacle. At this period the stream will cease, till the receptacle being again filled, will again exhibit the same appearance. And these periodical returns of flood and cessation will be regular, if the filling of the reservoir be so; but the interval of the returns must depend on the dimensions of the apparatus, and the quantity of influent water.

The action of that very useful instrument the pump, depends on the pressure of the atmosphere. It consists of a pipe CD (fig. 119.) whose lower end C is immersed in water: at B is fixed a clack or valve opening upwards, and in the superior part of the tube is worked a piston A, which by means of leather, fits very closely in the pipe. In this also is a valve opening upwards. Now, if the part above B be filled with water, to render the whole air-tight, the piston A being thrust down to B, and afterwards raised, a vacuum or void space will be left between B and A, into which the air contained in the lower part of the pipe CB, will expand itself. The spring of this air being thus weakened

weakened by the expansion, can no longer counterpoise the effect of the pressure of the atmosphere, and the water will rise in the tube till the equilibrium is restored. By depression of the piston A, the valve B is suffered to close, and a part of the air between the valve and piston escapes through A. After a few strokes, the whole of the included air is extracted, the water rises through the valve B, and is drawn upwards, and discharged by the piston A. And this operation may be continued at pleasure. But if the height BC be more than 34 feet, the water will not rise to the valve; for a column of fresh water of that length being equal to the weight of the atmosphere, it can be raised no higher by that weight. Thus also it is, that the mercury in the barometer stands but to a certain height; and if a pump finished with the utmost exactness on the above principle be made to work in mercury, it will not raise it beyond that height.

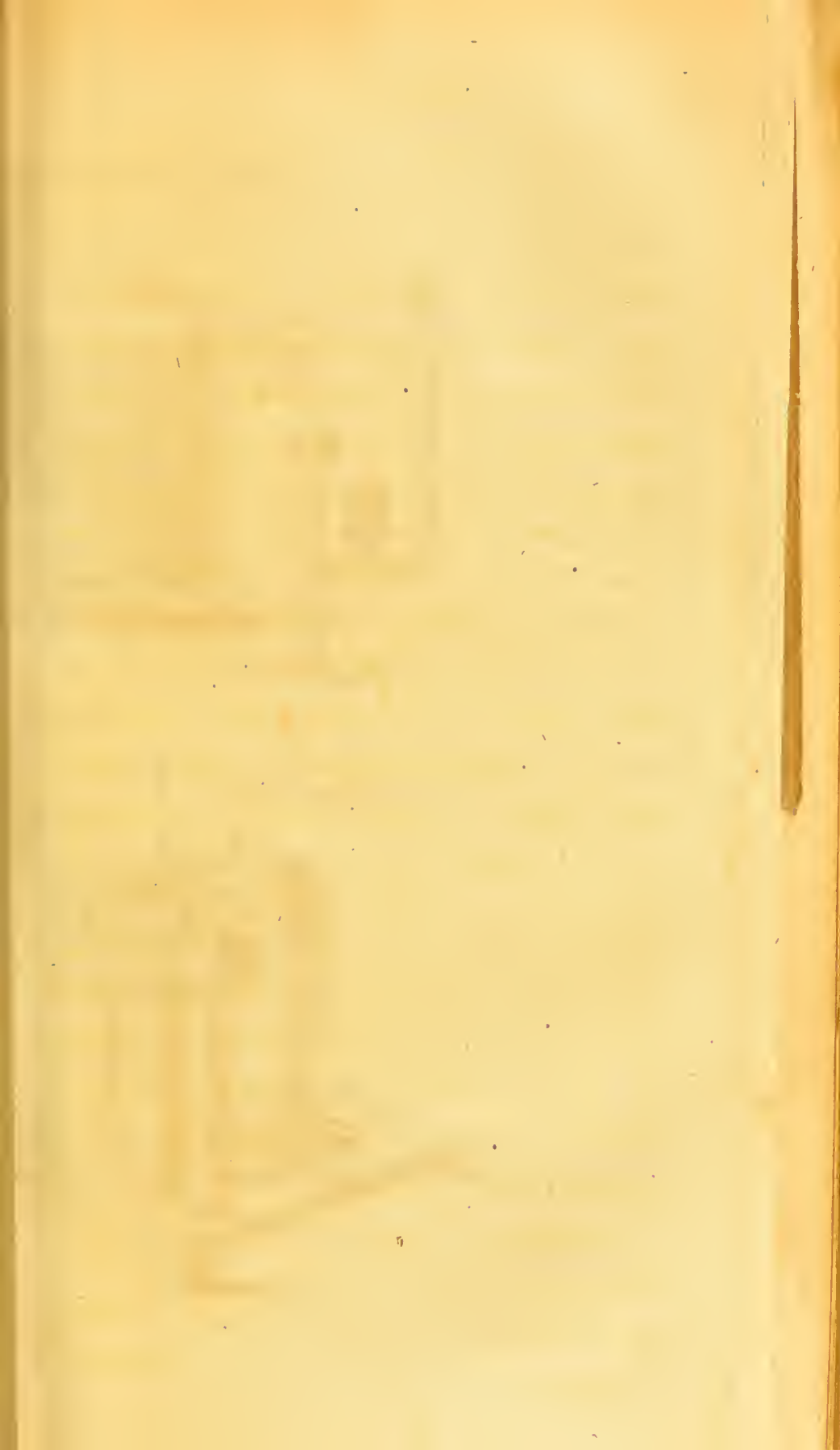
The fire-engine acts by means of the weight and elasticity of the air. For it is composed of two barrels, E and D, (fig. 120.) in each of which a solid piston or plunger

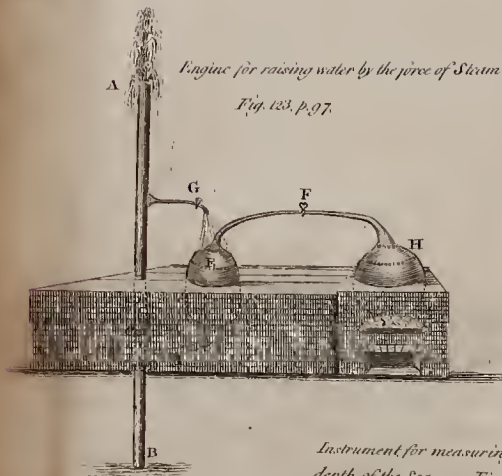
plunger is worked by means of a double lever. These barrels communicate with the water by a pipe not expressed in the figure: they also communicate with the strong cylinder or vessel CC, by the pipes L and T. At M and K in the barrels are valves opening upwards, and at L and T are valves which open towards the cylinder. In the figure, the piston in D being raised, the water rushes in at D, while that in E being depressed, forces its contents into the cylinder through the valve T. At the next stroke the barrel E raises the water, while the contents of the barrel D are forced into the cylinder: and thus the alternate actions of raising and forcing may be continued at pleasure. Now the water being forced into the cylinder, compresses the air contained within, into a small space; which air reacting on the water, drives it in a continual stream through the pipe POQR, which may be directed as necessity shall require.

That the force of compressed air is very great, appears by many experiments, particularly in the performance of the wind-gun. Fig. 121. represents a section of this instrument.

instrument. A K is the barrel, containing a ball at K. This barrel is contained within another larger tube CDRE, and in the intermediate cavity, the air is compressed and kept. MN is a cylindrical cavity in the stock or butt end of the piece, in which a piston works for the purpose of forcing the air into the before-mentioned cavity. The air is prevented from returning by the shut or valve P, which is opened by the air, as it is forced in, but at other times, is kept shut by the spring of the included air. At L is placed another valve, which, by means of a spring is pressed close on the orifice of the barrel, and prevents the air from escaping. To this valve is affixed a wire, which, passing through a hole that is rendered airtight by wet and greasy leather, appears afterwards at O, in the form of a trigger. When the trigger is drawn back, the valve L opens, and the air rushing out, drives the ball with a force that seems not much less than if it were discharged from a musquet.

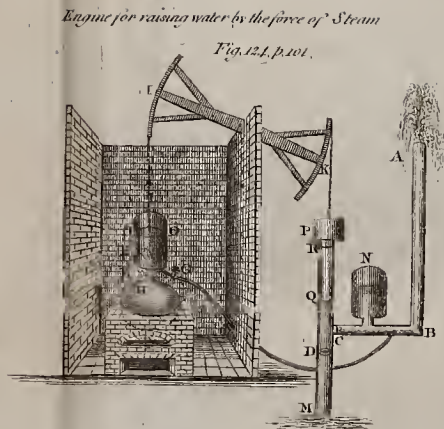
A variety of curious and pleasing fountains may be formed by the help of the properties of the air combined with hydrostatical principles.





Engine for raising water by the force of Steam

Fig. 123, p. 97.

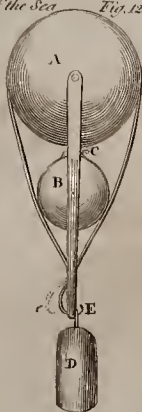


Engine for raising water by the force of Steam

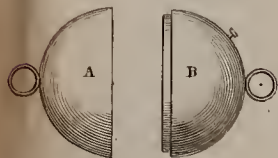
Fig. 124, p. 101.

Instrument for measuring the depth of the Sea

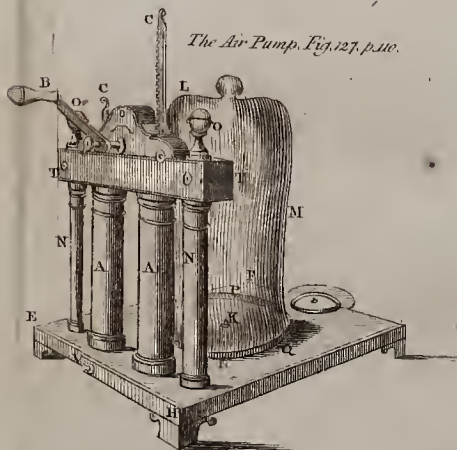
Fig. 125, p. 106.



Pressure of the Air Fig. 126, p. 117.



The Air Pump, Fig. 127, p. 110.



principles. The following is the most in esteem. ABCD (fig. 122.) is a copper vessel, near two-thirds filled with water : at M is screwed in, the tube IG, the junction being made air-tight by means of wet and greasy leather, and in the upper part of the tube is fixed a stop-cock H. The stop-cock being opened, a forcing syringe is screwed on at I, and a great quantity of air injected, whence the air in the cavity ABFE being very much condensed, presses on the surface of the included water. The stop-cock being then shut, the syringe is removed, and an adjutage screwed on in its place ; through which, if the stop-cock be again opened, the water will spout forth with great violence.

In many mechanical engines, where the force of an elastic fluid is required, the steam of boiling water is made use of, by reason that it is easily obtained, and is prodigiously elastic.

The first engine of which we have any account, for raising water by the force of steam, was constructed about a century ago upon the principle of the figure, (fig. 123.) in which H represents a copper boiler placed on a fur-

nace. E is a strong iron vessel which communicates with the boiler by means of a pipe at top, and with the main pipe AB, by means of a pipe I at bottom. AB is the main pipe immersed in the water at B. D and C are two fixed valves, both opening upwards, one of which is placed above, and the other below the pipe of communication I. Lastly, at G is a cock which serves occasionally to wet and cool the vessel E, by water from the main pipe, and F is a cock in the pipe of communication between the vessel E and the boiler.

The engine is set to work, by filling the copper in part with water, and also the upper part of the main pipe above the valve C, the fire in the furnace being lighted at the same time. When the water boils strongly, the cock F is opened, the steam rushes into the vessel E, and expels the air from thence through the valve C. The vessel E thus filled, and violently heated by the steam, is suddenly cooled by the water which falls on it upon turning the cock G, the cock F being shut, to prevent any fresh accession of steam from the boiler. In consequence of this, the steam
in

in E becoming condensed, leaves the cavity within almost intirely vacuous: the preffure of the atmosphere at B, therefore, forces the water through the valve D till the vessel E is nearly filled. The condensing cock G is then shut, and the steam cock F again opened; the steam rushing into E, expels the water through the valve C as it before did the air. Thus E becomes again filled with hot steam, which is again cooled and condensed by the water from G, the supply being cut off by shutting F, as in the former operation: the water consequently rushes through D, by the preffure of the atmosphere at B, and E is again filled. This water is forced up the main pipe through C, by opening F and shutting G, as before. It is easy to conceive, that by this alternate opening and shutting the cocks, water will be continually raised, as long as the boiler continues to supply the steam.

For the sake of perspicuity, the drawing is divested of the apparatus by which the two cocks are turned at once, and of the contrivances for filling the copper to the proper quantity. The engines of this con-

struction were usually made to work with two receivers or steam vessels, one of which received the steam, while the other was raising water by the condensation. This instrument has been since improved, by admitting the end of the condensing pipe G into the vessel E, by which means the steam is more suddenly and effectually condensed than by water on the outside of the vessel.

The advantages of this engine are, that it may be erected in almost any situation, requires but little room, and is subject to very little friction in its parts : its disadvantages are, that great part of the steam is condensed, and loses its force upon coming into contact with the water in the vessel E, and that the heat and elasticity of the steam must be increased in proportion to the height to which the water is required to be raised. On both these accounts a large fire is required, and the copper must be very strong, when the height to which the water is intended to be raised is considerable, otherwise there is danger of its bursting. The following engine, though in general bulky,
and

and more expenſive in its conſtruction, is leſs chargeable in fuel, as it acts by means of ſteam whoſe denſity is not much greater than that of the common air.

In fig. 124. H represents the copper boiler on its furnace. E is a cylindrical veſſel of iron, in which the piſton OO moves up and down; the edges of the piſton being armed with oakum and greaſe, render the whole cavity between the piſton and the bottom of the cylinder air-tight. F is a cock by which ſteam is occaſionally let into the cylinder from the boiler. IK is a lever, attached to the piſton at I, and at K to the piſton of a pump which works on that ſide. PQ is a ſolid piſton which moves in the pipe RM, and which is loaded with a heavy weight at P. ABC is the main pipe into which the water is forced from RM through a valve C opening outwards. N is an air veſſel communicating with the main pipe. D is a valve opening upwards, and at M is the water to be raiſed.

In the drawing, the engine is represented in the poſition which it has at the end of a forcing ſtroke, which is likewise its poſition

when at rest. Suppose the main pipe ABC to be filled with water, and the water in the copper H to boil strongly. The cock F being then opened, the steam rushes into the cylinder, and being much lighter than the air, rises to the top, and expels the air through a valve in the bottom of the cylinder. This being accomplished, F is shut, and the cock G communicating with the main pipe is opened, which immediately condenses the steam by violently spouting cold water against the bottom of the piston. A vacuum being thus obtained, the pressure of the atmosphere forces the piston down to the bottom of the cylinder; the lever IK is moved of course, the piston PQ with its weight is raised, and the water ascends in the pipe MR upon the principle of the common pump. The cock G being now shut, and F opened, the steam enters the cylinder, and counteracts the pressure of the atmosphere on the piston OO. In consequence of this, the weight P prevails, and drives down the piston RQ, which forces the water through the valve C into the main pipe and its air vessel. The use of the air vessel is to prevent the main
pipe

pipe from bursting by the sudden entrance of the water ; for the air at N being elastic, gives way in some degree to the stroke. By opening the cock G and shutting F, the steam is again condensed, the pressure of the atmosphere again prevails, and thus the work may be continued at pleasure.

In this drawing likewise, the mechanism is omitted, by which the cocks are opened and shut. This office is performed by a beam and ropes attached to the lever IK ; so that the attendance required is very little more than is necessary to supply the boiler with water, and to prevent the fire from going out.

The peculiar advantage of this engine is, that the water may be forced to any height without increasing the force of the steam, which never need be much greater than that of the atmosphere ; and therefore the boiler is very little endangered. The maximum of its power depends upon the area of the piston OO ; for the larger the area, the greater the column of the atmosphere by which it is pressed, and consequently the heavier the weight P may be. If OO be 36 inches in
H 4 diameter,

diameter, it will be pressed by a column of the atmosphere equal in weight to a column of mercury of that diameter, and 30 inches in height ; that is to say, almost 7 ton.

But, notwithstanding the great skill and contrivance displayed in this engine, it is at present almost entirely superseded by one of a much better construction, invented and perfected by Messrs. *Watt* and *Bolton*, of *Birmingham*. Those gentlemen seem to have carried the art of raising water, by means of steam, as far as it will go, both with respect to the theory and the execution ; but as they are yet only beginning to enjoy the fruits of their ingenuity and labour, it might be doing them an injury to publish a scientific description of their engine. We shall therefore content ourselves with observing, that instead of depressing the piston OO by means of the weight of the atmosphere, the steam is thrown upon it, the upper part of the cylinder E being closed, and the rod L, which is smooth and polished, being admitted through a perforation, which is wadded so as to be air-tight. The ascent of the piston is obtained by letting the steam out

of the cylinder into a vessel at a considerable distance, where it meets with, and is condensed by a jet of cold water ; while a vacuum is constantly maintained in the lower part of the cylinder by the action of an air-pump. The force of steam employed in this engine is usually equal to one atmosphere and a quarter, and the whole apparatus is regularly worked by the principal lever IK. The advantages of this construction are, that by increasing the force of the steam the power of the engine may be increased, without enlarging the diameter of the cylinder ; and a less expence of steam is required on account of the condensation being performed at a distance from the cylinder, which is not therefore cooled by the injection of the cold water. To these we may add the peculiar neatness and accuracy with which the apparatus is finished, which cannot but greatly contribute to facilitate the working of the engine. On these accounts, the expence of fuel is very much less than in any which have been hitherto constructed.

The elasticity of the air affords a method of determining the depth of the sea in places
where

where a line cannot be used. Fig. 125. is a machine for this purpose. A represents a large ball of fir or other light wood, varnished over, to preserve it from the effects of the water; B is a hollow glass vessel, whose contents in sea-water is exactly known; suppose, for instance, two pounds: its neck C terminates in a small orifice, and is bent downwards, to prevent the escape of the included air, when it is immersed in water. At E is a spring-hook, which, if at liberty, would stand in the position e, but which is pressed through a slit in the stem at the bottom, and kept to its place by hooking on the weight D. The whole instrument thus prepared is suffered to sink in the water. And the consequence is, that as it sinks, the pressure of the water continually increasing, forces its way into the vessel, and condenses the air contained within; but when it arrives at the bottom, the weight D striking first, is stopped, while the rest of the apparatus proceeds a little onwards, by reason of its acquired velocity. The hook E being thus disengaged from the weight, flies back, and leaves it intirely, by which means the ball A is at liberty to rise again

to the surface. By the quantity of water contained in B at its emergence, it is easy to determine the depth to which it has descended. For, since the density of air is as the compressing weight, the bulk of the same quantity of air under different pressures, must be reciprocally as the weight. And experiment shews, that the weight of the atmosphere is equal to 32 feet of sea-water: therefore, at the depth of 32 feet, the air included in the vessel C will sustain the pressure of two atmospheres, and consequently will be condensed into half its former space; at 64 feet depth it will sustain the pressure of three atmospheres, and be condensed into one third of its first space, and so forth. For example, suppose an empty ball as above described, capable of holding two pounds troy of sea-water, was to descend to an unknown depth in the sea, and at its return was found to contain 1 lb. 11 oz. 18 dwts. of water, it is required to find the depth? Then, As the bulk into which the air was compressed, when at the bottom of the sea, which is expressed by 2 dwts. Is to the bulk of the air before immersion, which is expressed by 2

lb.

1b. So is the weight of the atmosphere, by which the air was compressed before immersion, which is expressed by 32 feet of water, To the weight by which the air was compressed when at the bottom of the sea, 3840 feet. From which deduct 32 feet for the pressure of the atmosphere, and the remainder, 3808 feet, indicates the depth of the sea.

This method is subject to two objections. The first is, that probably the specific gravity of the sea may be different at different depths, in which case the pressures will not be as the depths: and the other is, that air in very great condensations does not strictly follow the ratio of the pressure, but resists in a greater degree. But a careful series of experiments may indicate the allowances which ought to be made on both accounts, and in small depths the instrument is sufficiently accurate on the principle already laid down.

If an empty vessel, that is to say, a vessel containing air, be immersed in water with the mouth downwards, the spring of the air will prevent the water from filling the vessel, as may be easily seen by the help of
a wine-

a wine-glass. The diving-bell is constructed to serve on this principle. It consists of a large vessel or kind of cask, so loaded with lead as to sink when empty, with the mouth downwards. In the top is fixed a cock to let out the air, and a strong pane of glass to afford light to the divers, who sit on a circular bench in the inside. This machine is lowered into the water about twelve feet at a time, and at each pause air is sent down in smaller bells to the divers, and by them received into the cavity of the great bell, for the purpose of expelling the water, which enters as the pressure condenses the included air. After it has arrived at the bottom of the sea, they continue by the same means to replenish the air which becomes foul by breathing, letting the impure air escape by the cock in the upper part, as they receive fresh air by the barrels or small bells; by which contrivance they can remain under water as long as they please. The diving-bell might be applied to good use in the pearl fishery, and in other affairs of that nature; but has not yet been applied to use, except by Dr. *Halley*, and a few other curious and philosophical gentlemen.

C H A P. VI.

Of the Air-Pump, and its Uses.

THE most useful of all philosophical instruments, whose actions depend on the properties of the air, is the air-pump. By the help of this machine all that has been shewn concerning the weight and elasticity of the air, is demonstrated in the most simple and elegant manner. Its construction is as follows : EFGH (fig. 127.) is a square table of wood, AA are two strong barrels or tubes of brass, which are firmly retained in their position by the piece TT, which is pressed on them by screws OO, which are fixed on the tops of the brass pillars NN. These barrels communicate with a cavity in the piece D. At the bottom within each barrel is fixed a valve, opening upwards, and in each a piston works, having a valve likewise opening upwards. The pistons are moved by a cog-wheel in the piece TT, to the axis of which

which the handle B is fixed, and whose teeth catch in the racks of the pistons CC. PQR is a circular brass-plate, in the center of which appears the orifice K of a concealed pipe, that communicates with the cavity; in the piece D at V is a screw that closes the orifice of another pipe, which also terminates at K, for the purpose of admitting the external air when required. LM is a glass-receiver, out of which the air is to be exhausted. It is placed on the plate PQR, which is first covered with a wet sheep-skin, or smeared with wax, to prevent the air from insinuating under the edge of the glass. We shall not describe the methods and precautions which are used to render the whole air-tight, but shall proceed to explain the mode of its action.

When the handle B is turned, one of the pistons is raised, and the other depressed; in consequence of which, a void space is left between the raised piston and the lower valve in the correspondent barrel: the air contained in the receiver LM, communicating with the barrel by the orifice K, immediately raises the
lower

lower valve by its spring, and expands into the void space; and thus a part of the air in the receiver is extracted: The handle then, being turned the contrary way, raises the other piston, and performs the same act in its correspondent barrel; while, in the mean time, the first mentioned piston being depressed, the air, by its spring, closes the lower valve, and, raising the valve in the piston, makes its escape. The motion of the handle being again reversed, the first barrel again exhausts while the second discharges the air in its turn: and thus, during the time the pump is worked, one barrel exhausts the air from the receiver, while the other discharges it through the valve in its piston.

Hence it is evident, that the vacuum in the receiver of the air-pump can never be perfect; that is, the air can never be entirely exhausted: for it is the spring of the air in the receiver that raises the valve and forces air into the barrel, and the barrel at each exsuction can only take away a certain part of the remaining air, which is in proportion to the quantity before the stroke, as the capacity of the barrel

barrel is to that of the barrel and receiver added into one sum. Besides which, there is another circumstance that impedes the perfection of the vacuum; namely, that there ever will be, in the best constructed instrument, a space between the two valves when the piston is down, in which a small quantity of air will remain. Now, when the air in the receiver is become so rarefied, that its spring is only equal to that of the small remaining quantity, when rarefied by raising the piston, it will not raise the lower valve, and of course the exhaustion will cease.

But though the vacuum in the receiver of the air-pump is not perfect, yet it is sufficiently so to exhibit most of the appearances which would take place in an absolute void; that is to say of air, for the particles of light, and probably other bodies, do exist in the vacuum here described.

There are several methods of discovering the degree of rarefaction of the air within the receiver. The best is by means of a bottle in the shape of a pear, which is graduated on the outside to every hundredth part of its contents. This bottle being filled with mer-

cury, a small bubble of air is admitted, and its neck is plunged in a vessel, likewise containing mercury. The pressure of the air sustains the mercury in the bottle, on the barometer-principle; but when the instrument is placed under the receiver, and the pressure diminished by the exhaustion, the included bubble is at liberty to expand by the fall of the mercury. And the degree of this expansion, which corresponds with that of the air in the receiver, is known by the graduations on the bottle. By an instrument of this kind it is found, that the air-pumps constructed in the best manner, as directed by Mr. Smeaton in the Philosophical Transactions for 1752, will rarefy the air more than 1000 times: but the common air-pumps in the shops seldom rarefy more than 100 times.

We observed, that the properties of the air might be very simply and elegantly demonstrated by the assistance of the air-pump. It will not be amiss in this place to enumerate some of the experiments which are made for that purpose.

The weight of the air is proved by exhausting it out of a bottle, as has already been observed.

served. It is also shewn, that the mercury in the Torricellian tube or barometer is sustained by the pressure of the air; for, if a barometer be placed under a tall receiver, and the air exhausted, the mercury will subside gradually as that pressure is removed. If a square bottle, in whose neck is fixed a valve, opening outwards, be placed under the receiver, and the air exhausted, the bottle will be crushed to pieces by the weight of the atmosphere when the air is permitted to return into the receiver: for the air being prevented from entering the bottle by the valve, the bottle (which, before the exhaustion, sustained the pressure of the atmosphere on its external surface, by means of the spring of the included air, which acted equally on the internal surface) being deprived of its internal air, is incapable of bearing the weight of the atmosphere which presses it on all sides. If the bottle were round instead of square, it would sustain the pressure, notwithstanding the exhaustion, by reason of its arched figure, which would prevent its giving way inwards.

The quantity of this pressure on a given surface is equal to the weight of a column of mercury, whose base is the given surface, and whose height is the height of the mercury in the barometer, as may be easily gathered from the hydrostatical principles heretofore laid down. To exemplify and prove this by the air-pump, it is usual to inclose in the receiver two brass hemispheres, as A and B, (fig. 126.) which shut together like a box, and which, at the place of shutting, are lined with wetted leather. The air being exhausted from the receiver escapes likewise from the cavity of the hemispheres, and when it is permitted again to enter the receiver, the hemispheres are so closely pressed together, that the air cannot enter at the place of junction: consequently they adhere together, with a force equal to the pressure of the atmosphere, which is greater or less in proportion to the area of the circle at the place of junction: thus, by the above rule, if the diameter of the circle at which the hemispheres are joined be four inches, the force required to separate them must exceed 230 lb. tröy.

Since bodies, immersed in fluids, lose parts of their weights, which are equal to the weights of masses of the fluids respectively equal in bulk to the bodies themselves, it follows that bodies of different specific gravities, which are in equilibrio in the air will not remain so in vacuo. For in vacuo each body will re-acquire the weight which they may be said to lose while in the air, and the body whose bulk is greatest will acquire the greatest weight. Thus, if a piece of cork be in equilibrio with a piece of lead, when weighed by fine scales in the air, the cork will preponderate in vacuo; the removal of the air adding proportionally more to its weight, as its bulk exceeds that of the lead.

The spring of the air may likewise be shewn, in various manners, by the assistance of the air-pump. If a small tube be inserted through the cork of a bottle, half full of mercury, so that the communication between the air included in the upper part of the bottle and the external air be entirely cut off, the end of the tube being immersed in the mercury; and this apparatus be placed

under the receiver and the air exhausted: then the spring of the included air, pressing on the surface of the mercury, will force it into the tube, and sustain it at the same height nearly as it stands in the barometer; the spring of the air being equal to its weight, and consequently producing an equal effect: but on account of the imperfection of the vacuum, the spring of the small remaining quantity of the air in the receiver prevents the mercury from rising exactly as high as it does in the barometer.

If a half blown bladder be placed in the receiver, the included air will expand, as the exhaustion proceeds, and will blow it up even to bursting. And if this bladder be inclosed in a box, whose cover is loaded with weights somewhat less than equal to that of the atmosphere, the expansion will raise the cover and sustain the weights. Thus if the bladder be inclosed in a box of 6 inches diameter, it will raise the cover, though loaded with upwards of 500 lb. troy, as may be easily gathered from the consideration, that the spring of the air is equal

to its weight; which weight may be found by the rules established above.

The spring of the air, which is included in the larger pores or vessels of bodies, is the foundation of a number of pleasing and instructive experiments. Thus it is found, that wood is specifically lighter than water, only by reason of the spring of the air included in its vessels, which prevents the water from entering: for when this air is extracted, and the water, by the admission of the external air into the receiver, is impelled into the vessels of the wood, it is always found to sink to the bottom.

The refractive power of the air is also shewn by the air-pump. For if the air be exhausted out of a prismatic glass vessel, the rays of light will not pass straight through its sides, but in entering the vacuum, are deflected from the perpendicular, and at their emergence into the air, are deflected towards the perpendicular, according to the established laws of optics. The proportions of the sines of the angles of incidence and refraction, out of the vacuum into the air, are by this means found to be as 100036 to 100000;

which is nearly the same ratio as that which is deduced from the refractions of the heavenly bodies.

It is likewise proved by the air-pump, that the air is the medium of sound. A bell or small alarm clock, being rung in the exhausted receiver, gives no sound, but if the air be admitted, the sound gradually becomes louder and louder, till the air in the receiver be of the same density with that of the atmosphere, at which time the sound is no otherwise weakened, than on account of the receiver by which the bell is covered.

We have frequently mentioned the resistance of the air. The quantity of this resistance is very considerable, and may be discovered by calculations grounded on the principles laid down at Ch. 4. Sect. 3. of this book. Were it not for this resistance, all bodies falling together from the same height, would arrive at the ground in the same time. This is shewn in the air-pump; for if a guinea and a feather be let fall together from the top of a tall exhausted receiver, they both arrive at the bottom at the same instant.

Among

Among the very numerous instances of the usefulness of this instrument, we shall mention but two more; namely, the discovery of the absolute necessity of air for the preservation of life in most animals, and for the production and continuance of flame. Most animals, when included in the exhausted receiver, are observed to die in about five minutes, though the time is various in different species, and they recover again for the most part, if the air be again admitted without being withheld too long. A lighted candle being placed under the receiver, is extinguished at the beginning of the rarefaction, and the smoke hovers about the top of the receiver; but when the air is still more rarefied, it subsides to the bottom, as being specifically heavier. Gun-powder may be lighted in vacuo, by means of a hot iron or a burning-glass, but it explodes grain by grain, in a different manner from what it does in the open air; and phosphorus shines even more in vacuo than in the open air.

B O O K III.

S E C T. I.

Of Chemistry.

THE phenomena which are explained in the foregoing part of this work, are chiefly such as dépend on a very few first principles, and are in general easily accounted for, by a synthetical reference to them. But that part of natural philosophy which remains to be considered, is still in the process of analyzation. It is difficult to abridge a science which is almost purely experimental, and which therefore consists of many facts and little theory; since every attempt at brevity must be attended with some omission, perhaps of importance. In this department of physics, error surrounds us on all sides.

When

When we attend to the specific properties of bodies, we continually find ourselves at a loss: and it is at present quite uncertain, whether figure, density, progression, vibration, and other mechanical affections, which we observe in aggregate masses, be of any great consequence to the actions which take place among the particles. We shall therefore proceed to treat of chemistry with that diffidence and caution which the intricacy of the subject demands.

C H A P. I.

Of Chemistry ; and the Methods of decomposing Bodies.

CHEMISTRY is a science which relates to those properties of bodies which seem to be specific, and do not apparently depend on any organization or evidently mechanical operation of their parts.

The obvious method of examining any compound subject is to attend separately to the parts of which it is composed. This method is adopted by natural philosophers in their enquiries into the properties of bodies.

The parts of some bodies may be mechanically separated from each other by pulverizing and immersing the powder in a fluid, whose specific gravity is intermediate between that of the several particles ; in which case they will be separated by the subsidence of the heavier : thus, clay and sand may be separated by means of water ; the sand immediately subsides, and the clay and water may be decanted

canted off. Powders may also be separated by filtration or straining, the larger particles remaining on the filter, and the smaller passing through. But this cannot with propriety be called decomposition, and is totally insufficient for chemical purposes.

If an uniform compounded body be supposed to be divided into the smallest parts which are possible, so that those parts may be of the same nature as the mass itself, the body is said to be mechanically divided, and these smallest parts are called integrant parts; but if the division be carried farther, the body is said to be decompounded, and the parts are called constituent parts or principles. Thus for example, sulphur is found to consist of an acid united with phlogiston, or the principle of inflammability: if this sulphur be imagined to be gradually reduced to the smallest particles, the division is said to be mechanical as long as the particles continue to be sulphur; when the division is carried so far that it cannot be continued without separating the particles of acid from the phlogiston, those smallest particles of sulphur are called its integrant parts; but

but when, by continuing the division, the particles cease to be similar, and are separated into acid and phlogiston, the body is said to be decomposed, and the acid and phlogiston are said to be the constituent parts or principles of the compound sulphur.

Numberless experiments prove, that the attraction of cohesion by which bodies are united into masses, is subject to very considerable mutations. The varying hardness, elasticity, &c. of different bodies, prove that its force is not uniform after the rate of the mass, like gravity. It is found to be stronger or weaker between different bodies in like circumstances; and the adhesion of the parts of the same body is greater or less, accordingly as the temperature of the body with respect to heat is less or greater.

The attraction, by which one body unites with another and forms a compound, is called its affinity with that body. These affinities are likewise termed elective attractions, on account of their variations of force with respect to different bodies: thus the affinity or elective attraction of water

to spirit of wine is greater than to nitre; for, if spirit of wine be poured on a strong solution of nitre in water, the water unites with the spirit, quitting the nitre, which immediately falls to the bottom in its proper form.

The quantity of the attraction of cohesion in the parts of the same body is susceptible of great variety, according to the temperature with respect to heat. If the heat exceed not a certain degree, the body is solid; if the heat be greater, the body is fluid or melted; a still greater degree of heat seems entirely to destroy the attraction, which is then turned into repulsion, and the particles consequently recede from each other, and the body puts on the form of an elastic fluid or vapor. The limits, at which these changes happen, differ exceedingly in various bodies. Some bodies, as quicksilver, require an extreme degree of cold to become solid; others, as air, continue elastic in every temperature we can obtain on earth; and, on the contrary, there are bodies, for instance, the calx of tin, which will not melt without the greatest heat.

heat. It is probable, that there are no two bodies which agree in these respects.

Those bodies which endure the utmost violence of heat without being converted into vapor, or enduring any change except in figure, are called fixed: those which easily rise in the form of vapor, are called volatile. These terms are merely relative. There is great reason to think, that all bodies might be converted into vapor by a heat sufficiently great.

Bodies are decomposed either by altering their temperature, or by the elective attraction of some other body. Thus, if there be two bodies, salt and water, for example, whose fixity is very different, a sufficient heat will destroy the attraction between them; and the water, being more volatile, will fly off in vapor. On the contrary, a great degree of cold will cause the salt to separate in part from the water, in its solid form, probably because the mutual attraction of the parts of the salt is more augmented by cold, than the attraction which subsists between the salt and the
water.

water. The second method of decomposing, is, by presenting a body which has a stronger affinity with one of the principles of the body to be decomposed than its remaining principles have. Common salt, for example, consists of two principles, which are known by the name of marine acid and mineral alkali. If the acid of vitriol be added, it unites with the mineral alkali, by means of its stronger affinity, and the marine acid flies off in the form of vapor.

It is evident, from all the phenomena, that the attraction of cohesion is greater, in like circumstances, the nearer bodies approach to each other. For this reason, the parts of a solid body must attract each other with more force than they can be attracted by another solid body which cannot be brought into any perfect or extensive contact with them. Cold therefore, by rendering bodies solid, prevents the elective attractions from appearing in any considerable degree: and on the contrary, the greater the degree of heat the more perfectly

in general do the affinities exert themselves; for fluid bodies or vapors may permeate and mix with each other in every possible manner.

C H A P. II.

Of Heat; and the Manner of performing chemical Operations.

SINCE heat is so universal an agent in all chemical processes, it will be necessary to enquire into its properties before we proceed to particulars.

Heat then is that state in which bodies are, when they convey a peculiar sensation to the organ of feeling, which is vulgarly known by the same term. The cause of that state is also frequently denoted by the same word; but we propose to confine ourselves to this single acceptance.

This definition of heat is relative to the sense of touch, and, as that sense varies in its notices, according to the temperature of the human body, it is by no means accurate

curate enough for philosophical purposes. Underground cellars, which appear cool in summer, are sensibly warm in winter; but the difference consists only in the relative heat or cold of the body of the observer with respect to the air in the cellar. Water which appears warm to one hand may seem cold to the other, if the hands be not equally warm; and in the autumn, when the winter is just beginning to approach, numbers think the weather exceedingly cold, while the perceptions of others are very little affected. These and other similar circumstances indicate the necessity of attending to other appearances which accompany the state of heat, and are less equivocal.

In a more enlarged and useful sense, it may therefore be proper to say, that heat is a state or temperature, in which the dimensions of uniform bodies are augmented; and the greater the augmentation the greater the heat is said to be.

But in what does this state consist? The increase of bulk is only a collateral circumstance. Does heat consist of particles of astonishing subtilty, which permeate the

denfest bodies without difficulty,—which, being endued with a peculiar and rapid motion, are in themselves essentially fluid, and the cause of agitation and fluidity in other bodies?—or, is it no more than a certain motion or vibration impressed on the parts of bodies, which prevents contact and cohesion in proportion as it is more or less violent; and which, if encreased beyond a certain degree, throws the particles out of the limit of attraction, and causes repulsion to take place? This subject is surrounded with difficulties.

It is usual to judge of the quantity of heat by the increments of the bulks of bodies. Thus, if the quicksilver in the tube of a thermometer be raised five degrees beyond a certain standard, by being immersed in a fluid, and after that, be immersed in another fluid, and raised by that means ten degrees, we say, the quantity of heat in the latter is twice as great as in the former fluid.

But this method of reasoning is erroneous: for whatever heat may be, the thermometer can only shew when the quantities in two bodies are equal, or indicate that one of the bodies is hotter, without fixing the ratio of the

the

the quantities of heat. The expansion of bodies very probably follows some direct ratio of the quantity of heat; but whether that ratio be simply as the increments of the bulks, or whether it follow any other law, has not yet been determined.

Heat seems to be a state of force on bodies. The action of the Sun causes that heat which prevents all bodies from congealing into absolute rigidity and inaction. And it is probable that there is no body on earth entirely deprived of heat. The means by which heat is produced, or to speak more properly, augmented, are first, the action of the rays of light, secondly, the collision of bodies, and thirdly, the mutual concurrence of two bodies, whose affinities to each other are very strong.

What can be more natural than to suppose, that the parts of bodies are put into a vibrating motion by the swift and repeated strokes of the particles of light?—Can the collision of flint and steel be performed without a very violent agitation at the place of contact?—And is not there the highest probability, when the particles of two fluids,

for example, water and the vitriolic acid, rush together by means of a strong affinity, that a great intestine motion must take place before the parts are respectively so situated, as that their mutual tendency shall be satisfied as much as circumstances admit? It is scarcely hypothetical, then, to affirm that heat is always accompanied with an intestine motion of the parts of bodies. And if this intestine motion be of itself sufficient to account for the phenomena of heat, why should we multiply causes, and call in the assistance of a fluid to which we must give a number of surprising properties, namely, continual activity, essential fluidity, and a subtilty so amazing, as to enable it repeatedly, without a possibility of deflection, to pass through the densest bodies, without leaving a trace of its having been there?

It is true that obscurity will always attend speaking concerning a subject which is very little known. We do not know the nature of this motion, nor how it is propagated, but its existence can hardly be doubted; and when we look without prejudice into the regions

regions of conjecture, it appears at least as easy to conceive, that bodies may be constructed to vibrate more or less readily, as that they should have greater or less capacities for imbibing a fluid called heat.

On the other hand, it must be confessed, that mere motion or its absence seems insufficient to account for the cold produced during the combination of water with sal ammoniac, or that very intense cold which is obtained by the evaporation of either.

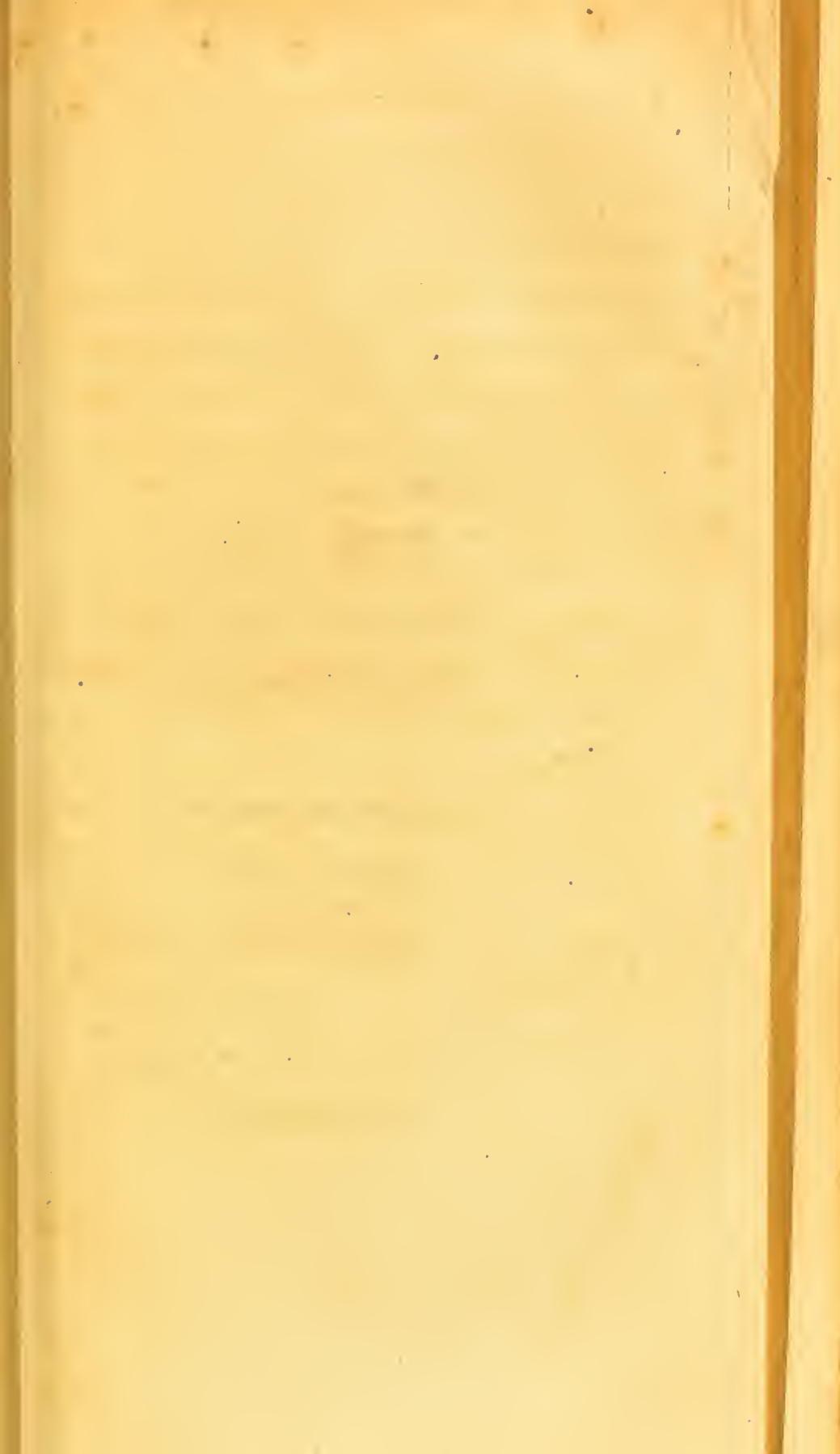
If a number of bodies possessed of various degrees of heat be put into contact, the heat is communicated from the one to the other, so that they will all, at length arrive at the same temperature. On this account bodies heated beyond the temperature of the circumambient air and vessel in which they are contained, must return to that temperature more quickly than they would otherwise do.

All fixed bodies, if heated beyond a certain degree, emit light and shine: and if certain bodies, which contain a principle called phlogiston, be made very hot, with access of pure air, the heat will increase, and be commu-

nicated without diminution, from one body to another, till the bodies are in a very considerable degree decomposed, and the phlogiston dissipated. This remarkable phenomenon is called combustion or burning.

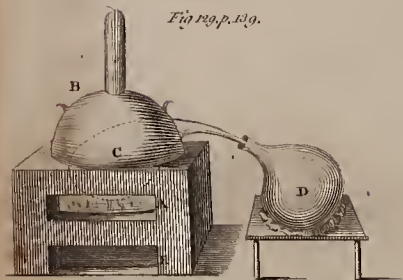
Does not this appearance greatly depend on the affinity between pure air and phlogiston? A certain degree of heat diminishes the attraction, between the phlogiston and the other principles of the body which contains it, and allows the affinity between air and phlogiston to take place. They rush together and exceedingly increase the heat, which must continue without diminution, as long as the body continues to afford phlogiston to combine with the air,

The most convenient practical method of producing heat in a given body, is by applying it to other bodies, which are in the act of combustion. A much greater degree of heat is procured by converging the Sun's rays by a lens or mirror, but the focus is not extensive enough to be generally useful. The heat produced by means of a flint and steel, seems to be even greater than
that



Reverberatory Furnace

Fig. 129, p. 139.



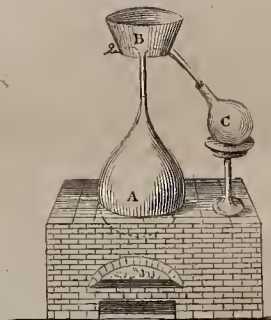
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Air melting Furnace

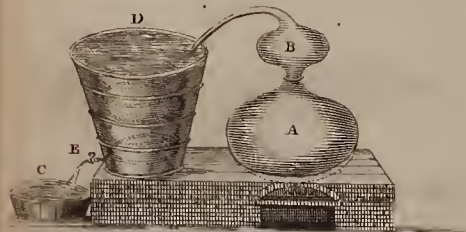
Fig. 127, p. 138.



Alclic Fig. 132, p. 140.



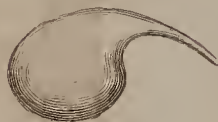
Alclic or Still, Fig. 133, p. 150.



Crucible Fig. 128, p. 138.



Saturation Fig. 134, p. 145.



Retort Fig. 130, p. 140.

that which is generally obtained by a burning-glass; for the sparks or particles of flint which are struck off, appear, when examined by the microscope, to have been completely vitrified, or reduced to glass. It may be readily imagined, that the heat, which, in an instant, produces this effect on a substance so refractory as flint, must be extremely violent.

Combustion depending so much on the access of air, it follows, that it must be more violent in proportion as the air is more plentifully supplied. Hence the use of the bellows. But in most processes in which fire is employed, it is inconvenient to use them, and yet a constant supply of air is necessary. For this purpose furnaces have been invented of a great variety of forms and magnitudes, according to the intention they were meant to serve. It will be sufficient to give a general idea without entering into a detail on this subject; we shall therefore describe only a few of the instruments by which bodies are exposed to the action of heat.

Fig. 127. is a vertical section of the air melting-furnace. A is the door of the ash-hole, B a grate at the bottom of the fire-place, which is covered at top with a flat stone, F. The communication between the chimney E and the fire-place is sideways at G; and the manner of its performance may be thus explained. The stone F being taken off, a crucible (fig. 128.) containing the matter intended to be melted or burnt, is placed on a stand at C, and covered with a tile: it is then surrounded and covered with burning charcoal, and the stone replaced at F. The heated charcoal rarefies the air contained in the fire-place, which becoming specifically lighter than the external air, must, upon the principles of hydrostatics, ascend up the chimney. A constant current of air therefore rushes through the ash-hole, and urges the fire; and this current will be more or less swift, the longer the column of rarefied air. If the cover be taken off at F, the air will make its escape almost immediately after passing through the fire, and becoming quickly cool, by the contact of the external

external air, the current will not be very rapid; but if on the contrary F be covered, the heated air will ascend through the long chimney E, without being much condensed. It will therefore be exposed a much longer time to the action of the air which presses in at B, and will continually increase its velocity till it issues with great rapidity at H. The current of air by which the fire is excited, will consequently be much more violent in this latter case than in the former.

In the opening or flue G, in the figure is placed a flat crucible D, somewhat resembling a salt-sellar. It is called a cupel, and is used by assayers for purifying gold or silver. Those metals are exposed together with lead to the action of the flame which passes through G: the heat vitrifies the lead, which combines with the baser metals, and soaking into the cupel, leaves the gold or silver in a state of great purity.

Fig. 129. is a perspective view of the reverberatory furnace. A is the fire-place, E the ash-hole, and B the dome by which the flames are reverberated or reflected on the

the

the upper part of the vessel C, denoted by the dotted curve line. The vessel C, of which fig. 130. is a drawing, is called a retort, and is usually made of glass or clay, according to the strength of heat it is intended to endure. D is the receiver, into which the nose of the retort is fixed by means of clay: this is also of glass, and has a small perforation in the upper part of its neck, to prevent its bursting by means of the rarefied vapors. The method of using this apparatus is obvious. The subject to be analyzed is put into the retort, and exposed to the fire; the volatile parts rise in the form of vapor, and pass over into the receiver, which being cold, condenses the greater part of them into a liquid. But if the body be of such a nature, that its volatile principles adhere too strongly to its fixed part, the volatile parts must be detached by means of an additional substance, whose elective attraction towards the fixed part is greater. This has already been observed in the last chapter, and the instance there adduced will again serve our purpose of explanation. Pure common salt,

salt, which consists of the fixed mineral alkali, and an acid of considerable volatility, called the marine acid, will endure a very strong fire without being decomposed, but if the acid of vitriol be added, its stronger affinity with the mineral alkali will form a new compound, called Glauber's salt; and the marine acid being detached, will easily arise in fumes and become condensed into a fluid in the receiver. This process is called distillation.

If a body being exposed to the action of fire, rise either entirely or in part, and the volatile fumes becoming condensed into a dry powder adhere to contiguous bodies; as for example, a part of burning fuel adheres to the chimney in form of soot: the process is called sublimation, and the powder is called flowers. Thus flowers of Benjamin, flowers of antimony, &c. are parts of those substances which are raised by sublimation.

It may seem strange at first consideration, that heat, which diminishes the attractions of the parts of bodies, should cause several affinities to exert themselves
which

which were not apparent in a colder state: but not to mention the reason alledged at the conclusion of the last chapter, it seems natural to imagine, that the weaker affinities are destroyed by less heat than the stronger. Thus the affinity between the marine acid and the mineral alkali being destroyed by a degree of heat which is insufficient to destroy the affinity between the acid of vitriol and mineral alkali, this last affinity must exert itself much more evidently than before.

It is not probable that bodies have any chemical action on each other, except when one or more of them is either in a fluid or vaporous state. When a solid body is combined with a fluid, it is said to be held in solution, or dissolved in the fluid. In this state of solution bodies diffused in fluids are actuated according to their affinities with each other, and with the fluid which sustains them. The method of analyzing or compounding by means of a fluid whose temperature does not considerably differ from that of the atmosphere, is called the moist way, in contradistinction to the other method, in which a strong heat is used, and which is termed

termed the dry way. The intermediate fluid by whose means the affinities are exhibited is called a medium ; but when its power of dissolving is only adverted to, it is called a menstruum.

As the effects of the mutual attraction between two loadstones are not seen while the loadstones lie on a table, but become evident as soon as they are made to float at liberty on the surface of water ; so the affinities between the parts of two bodies, which are held in solution, and move readily in all directions in a menstruum, may become manifest upon a similar principle.

A menstruum at a given temperature will hold in solution no more than a limited quantity of any substance. This quantity depends on the temperature of the menstruum, and the affinity which obtains between it and the body to be dissolved. A menstruum is said to be saturated with a body when it has dissolved as much as it can sustain ; and, perhaps universally, a saturated menstruum will not dissolve any additional quantity of the matter it is saturated with. An increase of heat in general causes a men-
3 struum

struum to dissolve and sustain more than it otherwise would. This seems to contradict the general position, that heat diminishes the attractions between bodies ; but if we advert more minutely to the circumstances of the fact, this conclusion will not appear to be well founded. Let us suppose, for an instance, that salt is the substance with which it is proposed that water shall be saturated. It is evident, that if the attraction between the particles of the salt respectively, were stronger than that which obtains between them and the particles of water, the salt would retain its solid form ; that is to say, it would not be dissolved. But it is dissolved ; and therefore the affinity between the water and salt is the stronger : consequently the salt must be disunited or dissolved by a force which is the difference between these two attractions : and since heat, as has already been observed, destroys a weaker sooner than a stronger affinity, the proportion of the stronger to the weaker must continually increase as the latter approaches to destruction. The effects must likewise increase, from whence it will happen, that the heated menstruum will more readily

readily dissolve, and sustain in greater quantity, than when cold.

It is manifest that the attractions on which chemical appearances depend, must diminish while the distance of the particles increases; for, otherwise we should perceive their effects between remote bodies of sensible magnitude. The phenomenon of saturation may probably depend on this property. Let A (fig. 131.) represent a particle of water, and B, C, D, E, F, G, particles of salt adhering to, and surrounding it. The particle H, therefore, being of necessity prevented from coming within a certain distance of A, will be but weakly attracted. If the attraction of A on H in this situation, be insufficient to detach it from the mass I, K, L, M, &c. the particle A may be said to be saturated.

But if instead of H, a particle of entirely another nature be presented, with which A has a greater affinity than with B, C, D, E, &c. it may be attracted so as to become attached to A without removing those other particles: A being saturated with particles of one kind, may therefore notwithstanding hold others of a different kind in solution. Or, if

this last affinity be supposed much greater, the particle may force itself between C and D, and by removing one or more of the contiguous particles out of the sphere of attraction, cause it to fall to the bottom of the fluid. And so of other particles.

It may be necessary to remind the learner, that these kind of speculations which relate to the particles of bodies, are in a great measure conjectural, and are to be made with prudence and caution. A person of a lively imagination may easily acquire a facility at making them, and by that means indulge a passion for hypothetical theory, which will soon deprive him of that sceptical and cool spirit of enquiry which is the first requisite in a philosopher.

When a body of sufficient magnitude is immersed in a menstruum, already saturated with some other body with which the menstruum has a less affinity than with the body last immersed, it will let go the first body, or some of its principles, and dissolve the other. The body, which thus falls to the bottom in the form of powder, is said to be precipitated, and the powder, if it differ from
the

the body first dissolved, is called a precipitate. For example; if copper be immersed in the acid of nitre, previously saturated with silver, the copper is dissolved, and the silver is precipitated in its natural state, but in powder. But if instead of copper an alkaline salt be immersed, the silver is precipitated in the form of a white powder called precipitate of silver: in this latter case the silver leaves a minute proportion of one of its principles in the acid.

Organised bodies, that is to say, vegetable and animal substances, consist of a mass of various compounded fluids contained in certain vessels. These bodies are conserved during life, by means very little known to us; but when the vital motion ceases, the fluids change, the solids are destroyed and in a great measure dissolved, decompositions ensue, and a variety of new combinations take place. The heat of the atmosphere is commonly sufficient to effect this change, which is denoted by the general term fermentation.

Fermentation taking place only in very compounded bodies, is by no means well understood: it is usually distinguished into

three different stages; namely, first, the spirituous or vinous fermentation, in which a great quantity of noxious or fixable air is detached from the mass, and a very volatile and inflammable substance, called spirit, is produced, which is easily separated by distillation. Secondly; the acetous fermentation, by which the mass is rendered sour, and vinegar is produced. And thirdly; the putrefactive fermentation, in which a large quantity of pungent volatile alkaline salt is produced. These stages always succeed each other in the above order. Bodies susceptible of the vinous may afterwards undergo the acetous, and lastly, the putrefactive fermentation; but there is no possibility of inverting the order. Bodies which are in the state of the acid fermentation, though they may not have undergone the vinous fermentation, are only capable of proceeding to the putrefactive fermentation; and those which directly acquire the putrefactive fermentation are incapable of either of the others.

The most volatile of all substances, permanently elastic vapor, or air excepted, are those which are obtained by fermentation.

The

The reverberatory furnace is calculated for extricating the volatile parts of such substances as require a great heat for that purpose. But for obtaining the volatile products of fermented bodies, the form of the apparatus is considerably varied. Fig. 132. is an alembic or still. A denotes the body or cucurbit, placed on a furnace, and the dotted lines at B represent the head which is environed by a vessel called the refrigeratory or cooler. The head is contracted into a beak, nose or spout, on one side, which passes through a hole in the refrigeratory, and is inserted in the neck of the receiver C. This apparatus is in general made of copper, except the receiver C, which is of glass. On the whole, it differs from the reverberatory furnace and its vessels in being adapted to raise and condense none but very volatile fumes. For this purpose the fire is less, and the neck of the cucurbit is longer, and terminates in a head which is kept constantly cool by means of water poured into the refrigeratory, and frequently changed. But the alembic of this form is not much in use at present; the following being more convenient,

A (fig. 133) is the body of the still, B its head, D the worm-tub, and C the receiving-vessel. The still-head terminates in a pipe, which is bent into the worm-tub in a spiral coil, called the worm, as may be seen by the dotted lines, and to the lower end of the worm is affixed a cock E. The rationale of this is obvious; for the worm-tub being filled with water, the worm is kept constantly cool; the vapors therefore which pass over from the still are condensed in their course through the spiral tube, and are discharged in a fluid form by the cock E into the vessel C. This is the still in use by the distillers of malt spirits. A certain quantity of the extract of malt, which has undergone the vinous fermentation, and is called wash, is put into the still, from which, by a moderate heat they obtain a weak spirit, called low wines, on account of its being combined with much water.

It very often happens, that when two substances are combined together, the compound partakes of the properties of both. Thus, if volatile matters, which enter into a compound be urged by a quick heat, they will in many cases carry up substances, which if alone
would

would not have been raised at that temperature. These matters may be separated by a more accurate management of the heat in a second distillation. In the present instance, for example, the spirits may be raised from low wines by a heat which is not sufficient to volatilize the water. This process is called rectification, when we speak of the volatile body, but when the fixed body is alluded to, it is called concentration. Ardent and volatile spirits being deprived of part of their superabundant water, are said to be rectified; but the acid of vitriol, which is so fixed as to be almost capable of ignition, is said to be concentrated when a great part of its superabundant water is driven off by heat. The term concentration is also applied to that separation of water, from some liquids, which is effected by freezing. The ice of vinegar exposed to freeze is almost pure water: this being separated, the remaining vinegar is much stronger, and is said to be concentrated. It is affirmed that spirituous liquors, as wine, or even beer, may be concentrated by the same method.

C H A P. III.

Of chemical Elements; or the classing of those Bodies which are less compounded than all others.

IN the decomposition of bodies, the principles or constituent parts are by no means so various as might be imagined. In fact, the analysis of all substances, however different, affords principles so exceedingly similar, that chemists have been ready to conclude that all bodies are composed out of a very few elements, and that the sensible differences arise only from the proportions of each that obtain in the several combinations. This opinion has the highest probability in its favour, but from the nature of things it is impossible for us to be ever assured that we are arrived at the elements or first principles of bodies. This is a theme on which many respectable philosophers have indulged a passion for theoretical conjecture, perhaps too much.

Since that separation of the principles of bodies, in which the chemical analysis consists, can only be effected by means of the
elective

elective attractions, or by heat, it is evident that instances must occur in which we shall be unable to obtain it. For example. Suppose two principles of equal fixity, or so fixed as to endure without alteration the strongest heat we can produce, be combined together by an elective attraction, which in each is stronger than its elective attraction to any other body, how are these principles to be separated? If they be exposed to heat they will either rise together unaltered, or both remain fixed: and if any third body in nature be added, no decomposition can take place; for, by the condition, the two combined principles attract each other more strongly than they do any other body. Here it may, on the contrary, be observed, that we may come at the knowledge of the elements by composition; for if any two bodies when combined shall produce a compound altogether similar to the body under examination, we may from thence infer, that it is composed of the same principles: but, in answer, it must be noticed, that the existence of such uncombined principles being a circumstance totally unconnected with, and independent of the principal fact, and
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the making the experiment being in a very great measure casual, we must in by far the most part of such instances be subject to uncertainty: and that more particularly, because the method of composition supposes a simplicity in the principles made use of, which can never be proved, since the method of analysis has been shewn to be insufficient for that purpose.

Without entering therefore into any detail concerning the chemical elements, or universal first principles, with which it is probable we shall long remain unacquainted; we shall proceed to enumerate such as experiment has shewn to be much more simple than other bodies. These are, water, phlogiston, earths, acids, and alkalis.

Chemistry is not yet sufficiently advanced to enable us to determine whether these be the principles of all bodies; but it is certain that in the analysis of every different substance we at length arrive at principles which may with propriety be classed under some of these heads. Hence we conjecture, that these principles, universally similar to themselves, and these only, enter into the composition

tion of all bodies, and that our being unable to exhibit them perfectly similar is to be attributed to combinations, which the imperfection of the methods we make use of prevents our resolving. These principles are likewise to be regarded as simple, till future researches shall evince the contrary.

The true use of hypotheses being to systematize and direct our future enquiries, this general method of abstracting must be of great service; but at the same time we must be careful not to deceive ourselves by taking it for granted, that bodies, which resemble each other sufficiently to come under the same class, are really, though not apparently, similar in every other respect. Experiment alone must ascertain this supposition, and much remains yet to be done. From these and similar considerations it is evident, that the general division of bodies is not of any very great consequence to science in its present imperfect state; and therefore that the controversies and differences among chemists concerning first principles have tended but little to the advancement of knowledge.

The

The first of these principles, namely, water, is a very fusible and volatile substance. It assumes the fluid state in a less degree of heat than is necessary for vegetation, and is therefore in general met with in that state. It is then very transparent, inodorous and tasteless. When its heat is diminished to a certain degree, it becomes solid; not uniformly through all its substance at once, but some of its parts first assume a solid form in the shape of needles, crossing each other at an angle of sixty degrees, which continue to increase in number till the whole mass of water is become solid. This act is called congelation, and the solid mass, which is called ice, is much less transparent than before, and is augmented in magnitude about one tenth part. It is probable that the configuration of these needle-like parts may leave many invisible vacuities in the ice, by which its magnitude is increased, and its transparency in a great measure destroyed; but, however this may be, the expansion is made with a force so amazing, that no vessel has yet been found strong enough to resist it. The honourable

Robert

Robert Boyle burst a pistol-barrel, and Dr. Hales burst a bomb, the metal of which was one inch and a quarter thick, by freezing water contained within them.

Water in its fluid state is elastic, and may be condensed by pressure. When the pressure is removed it recovers its former dimensions. But the difference of magnitude produced by the pressures we are able to apply, compared with its magnitude when uncompressed, except by the gravity of its parts, is so extremely minute as to be almost inconsiderable.

The heat of water, and indeed all fluids of considerable volatility, may be increased to a certain degree, at which they become much agitated, and emit bubbles. This is called boiling, and happens at less degrees of heat accordingly as the fluid is more volatile. In open vessels, fluids which are capable of boiling, cannot at that period be made to receive any increase of heat; but in close and very strong metallic vessels water may be heated almost red hot. Upon this principle, the lighter the atmosphere the sooner the water boils; and if water, which has just ceased to boil, be placed
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in the exhausted receiver of an air-pump it will boil again for some time, on account of the pressure of the atmosphere being removed.

This stationary or fixed point of heat is justly attributed to the copious evaporation. In fact, all evaporation produces cold. The water, therefore, is in no case so much heated by the fire, as it would have been if no evaporation had taken place. The greater the evaporation the less the effect of the fire: whence it follows, that at a certain period the evaporation must be so great, as that the effect of the fire shall be no more than just sufficient to preserve the heat of the water, without augmenting it. And in other fluids, this event must happen soonest in those which are most susceptible of evaporation, or more volatile.

The production of cold, by evaporation, is a strong argument in favor of those who affirm that heat is something more than a mere motion of the parts of bodies. How, say they, can cold be produced by evaporation, unless heat be a substance which is carried off by the vapors?

Water being susceptible of two such remarkable changes as congealing and boiling,
and

and that at degrees of heat which it is not difficult to produce, affords an excellent method for settling the fixed points of thermometers. For the heat at which water congeals, and likewise that at which it boils strongly, under equal weights of the atmosphere, are precise and invariable; and consequently thermometers may be easily graduated from these two states of heat, so that they shall always agree in like temperatures.

When water is rarefied by heat into the form of elastic vapour, it is called steam, and is more elastic the more it is heated. When the elasticity of steam is equal to that of common air, it is much less dense than the air, and consequently must ascend. It has already been observed, that this elasticity of steam is turned to good account in the engine for raising water out of mines, &c.

If water be not a simple element it is compounded of principles whose mutual affinity is so great that they have never yet been separated. When it is distilled, either separately, or together with other matters, it is always recovered again in the form of water;
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so that it is usually said to be unalterable and indestructible.

Some philosophers, by repeated distillations of water, have procured an earthy sediment, and have from thence concluded that it was transmuted into earth: but it is generally thought, and there are experiments in confirmation of the opinion, that the glass-vessels being abraded or dissolved, may furnish the earth, which is found to be of the nature of glass.

Water has an affinity with a very great number of bodies, and for that reason is never met with naturally free from heterogeneous matters, or absolutely pure. The purest waters are rain and snow; but for nice purposes, water carefully distilled with a gentle fire is to be preferred to all other.

The next element, phlogiston, is by many chemists termed fire; and in order to distinguish it from heat, which they likewise call fire, the phlogiston is called combined fire, while heat is denoted by the terms elementary fire. But this manner of expression presupposes a certain theory of fire, which

is by no means established. We are ignorant whether heat be a mode or a substance; and to use the same term to express both it and phlogiston, which; in fact, is no more than the principle of inflammability, must tend to confuse our notions, and betray us into a persuasion that we know more of the subject than we really do. It will therefore be necessary to keep as near the facts as possible.

Phlogiston is that by which bodies, when in contact with pure air, and heated to a certain degree, are put into a state of combustion, during which they are in a great measure decomposed, and most commonly, or perhaps universally, exhibit an appearance of flame.

Bodies may be divided into two classes, combustible and incombustible: the latter are only capable of being ignited, or made red hot, and begin to cool immediately upon removing the cause of their heat; whereas the former, when considerably heated, with access of air, become inflamed, and continue to produce heat for a certain time, at the end of which they are, either entirely or in a great measure, deprived of that which made them

inflammable, and are reduced to the other class of incombustible bodies.

To vindicate the admission of the cause of inflammability, or phlogiston, among the elements, it will be necessary to shew, that it is a substance, and not a mere modification of the parts of bodies ; and that it is universally so similar to itself as to be easily distinguished in all the various bodies which are combustible. For this purpose let us attend to the circumstances attending combustion, and from thence make our inferences.

First, All combustible substances which can be exposed to great heat in close vessels, cannot, in that situation, be calcined or burnt; and in the open air the calcination is more quickly effected accordingly as the supply of pure air is greater. Secondly, If a combustible substance be inflamed, and afterwards included in a vessel, with a small quantity of atmospherical air, the combustion lasts for a certain time, and then ceases ; this time, and consequently that part of the mass which becomes calcined, is greater or less according to the quantity of pure air included ; and at the end of this time the air is found

found to be decomposed, part being fixed and precipitated, and the remainder, which is about four-fifths of the original quantity, is so changed as to be unfit for the purpose of assisting combustion, and is in some degree noxious. Thirdly, Sulphur may by combustion be deprived of its inflammable principle, by which means it is converted into the vitriolic acid; and again, the vitriclic acid, being properly treated with any inflammable substance, may regain the phlogiston, and be converted into sulphur, which sulphur is possessed of the same properties, however different the properties of the inflammable substances may have been by which the phlogiston was furnished. Lastly, the calces of fixed compounds, as metals, may be restored to their original state, by being treated with some inflammable substance; and the metal is in all cases the same, however various the phlogistic substances may have been by which it was revived.

The natural deduction from these facts appears to be, that phlogiston is a substance which is very simple and similar to itself.

For what can the enclosing a combustible body in a close vessel do, but prevent the dispersion of some substance? If calcination be no more than a change in the arrangement of the parts of bodies, why should not heat affect this as well in close as open vessels? Is it not evident in the second instance, that the phlogiston becomes combined with the compounded fluid air, and causes it to deposit one of its principles in the form of fixable air, while the calcination of the inflamed body goes forward; and does not the combustion cease when the remaining principle or principles of the air, being saturated, are incapable of receiving any more phlogiston? When sulphur, by combustion, is transmuted into vapors, which when condensed by means of water, and afterwards concentrated, are found to be the vitriolic acid, ought we not to conclude, that this very inflammable substance is converted, into a substance which is not at all so, by having lost one of its principles, namely, phlogiston? But when, on the other hand, the converse of the problem is effected, by producing sulphur from a well
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managed combination, of the vitriolic acid with the inflammable principle of some other body, we can hardly retain a doubt of the existence of this substance, and at the same time learn, from its effects, that it is similar in all inflammable bodies. And this familiarity of the phlogiston is still more evident from the reduction of the calces of metals; for if a metalline calx be properly treated with any inflammable substance, the external air being excluded, the metal, from which the calx was originally made, will be reproduced, as we have already observed.

The phlogiston of inflammable bodies being separable only when those bodies are in contact with others with which it can combine; it is not probable that we shall ever be able to obtain it in an uncombined and detached state. But it is by no means proper to speak decisively upon a subject in which so much remains yet to be investigated.

Earth is distinguishable from all other substances by its great fixity. If it be a simple substance, it has not hitherto been exhibited alone and uncombined; and con-

frequently there are many kinds of earths, which agree in the general property of fixity, but vary in several other respects. But we do not propose to enumerate and describe them in the present chapter, and shall therefore speak only of the general characters which are observed in bodies of this class.

There are few substances, if exposed to violent heat, but will leave a residue, or, as the ancient chemists called it, a caput mortuum, which consists, for the most part, of very fixed matters. That part of the residue which is either not at all, or with great difficulty, soluble in water, is called earth. Thus the calces of metals are called metallic earths, and precious stones, quicklime, plaster, clay, &c. are all earths, which resemble each other in the properties of fixity and difficult solubility in water, and differ in other particulars. The hardest bodies in nature are of the class of earths.

Acids compose the next class of simple bodies. These are so denominated from their taste, which is acid or sour, and are very numerous. There is some reason to
imagine

imagine that one primary acid exists, and that all the others are combinations of this primary acid with other substances; but till this conjecture be more confirmed, we must consider them as distinct and independent matters, which, from the resemblance of their properties, are classed together. The general and distinguishing properties of acids are, 1. They affect the organ of taste with a very peculiar sapidity. 2. Their affinity with water is so great, that they cannot be exhibited in a dry and dense uncombined form. 3. Concentrated acids added to water produce heat, if the water be in a state of fluidity, but, on the contrary, if it be frozen, they produce extreme cold. 4. When much concentrated, they may be combined with phlogiston. 5. They have a strong tendency to unite with almost all bodies: hence they are very corrosive, and form the most active menstruums. 6. They change the blue colours of vegetables and of their infusions to a red. Thus, the syrup of violets, the tincture of heliotropium, and other similar infusions, are generally used to discover the presence of an unsaturated acid

in bodies; but this criterion, though the most universal for that purpose, is not absolutely so.

From the distinguishing properties of acids, it has been suspected that pure acid is a combination of earth and water.

The last general species of bodies are alkalis. The four kinds of substances just enumerated are so far simple, that we have not been able to decompose them, so as to determine their primary principles with the smallest degree of accuracy. But in alkalis the case is different. They are procured by evident combination, namely, by the burning or putrefaction of substances in which they did not exist before, at least in any considerable quantity. And they may be decomposed. Yet, because the fixed alkali is capable of passing unaltered through a vast variety of chemical processes, and has strong affinities to many substances when in an uncombined state, we have thought proper to arrange it in this place.

The chief properties of alkalis are, 1. They affect the organ of taste with a burning, urinous taste. 2. They have a strong affinity

affinity with water, but may be easily obtained dry. 3. They produce heat by adding water to them. 4. They may be fused with a moderate heat, and in that state dissolve all earths. If the alkali be in a large proportion, the mass or solution assumes the alkaline properties; but if the proportion of earth prevails, its properties obtain, and the mass takes the form of glass. 5. If they be dissolved in water, an earth is separated, and falls to the bottom; and if the dissolved part be dried, and again dissolved, more earth is separated; and so on for any number of times. 6. Their affinity with acids is so great, that they unite with them, howsoever they may be combined, and even detach them from every substance except phlogiston and water. 7. They change the blue colours of vegetables, and their infusions, to a green; but this criterion is not without its exceptions.

From the methods by which alkalis are procured, and the concomitant circumstances, it is pretty well decided, that they are compounded of acid, of earth, and of a small proportion of phlogiston.

In the enunciation of sciences which depend upon established first principles, the nature of the subject dictates the order and arrangement. Simple truths are followed by more complicated deductions, in a natural and beautiful succession. But in the infancy of knowledge, especially that which depends upon experiment, every truth appears independent and cotemporary, while each attempt at explanation or analogy seems to demand a previous knowledge, in the learner, of all that has been done in the same way. Such is the state of chemistry; and therefore, to preserve that order which is essentially necessary to the conveying a general idea of science, we have endeavoured to speak cursorily upon almost every particular, and shall be more minute as we advance. The properties of earths, acids, and alkalis must be again resumed, and in the mean time, we conclude this chapter with the following table.

T A B L E

O F

DENSE SUBSTANCES PRODUCED BY COMBINATION.

WATER		PHLOGISTON	
combined with	produces	combined with	produces
Phlogiston	Ardent Spirit.	Water	Ardent Spirit.
Phlogiston & Acid	{ Refins. Oils. Ether. Lime Water. Plaster.	Earth	Coal.
Earth		Earth	Metals.
Earth and Acid	Salt.	Acid	{ Sulphur. Phosphorus.
Acids	Fluor Acids.		
Acid and Alkali	Neutral Salt.	Acid and Water	{ Refins. Oils. Ether.
Earth and Alkali	Liquor of Flints.		
Alkalis	Fluor Alkalis.		

EARTH	
combined with	produces
Water	{ Lime Water. Plaster.
Water and Acid	Salt.
Phlogiston	Coal.
Phlogiston	Metal.
Acids.	Salt.
Alkali and Water	Liquor of Flints.
Alkali	Glaſs.

ACIDS		ALKALIS.	
combined with	produce	combined with	produce
Water	Fluor Acids.	Water	Fluor Alkali.
Water and Earth	Salt.	Water and Acid	Neutral Salt.
Water and Alkali	Neutral Salt.	Phlogiston	
Water & Phlogiston	{ Refins. Oils. Ether.	Sulphur	Liver of Sulphur.
		Oils	Soap.
Phlogiston.	{ Sulphur. Phosphorus.	Earth and Water	Liquor of Flints.
Oils	Soap.	Earth	Glaſs.
Alkali	Salt.		
Metals	Salt.		

C H A P. IV.

Of Earths.

THOSE substances which are comprised under the general name of Earths, are very numerous and different, and the subdivisions of this class have consequently been various. Some authors have endeavoured to simplify the arrangement, and reduce the several kinds of earth to one or two general heads; while others, more minutely attentive to the differences, have been as careful to enlarge their catalogue. This Aristotelian element is met with in a prodigious variety of forms: stones, metals, clays, animal and vegetable substances, all furnish a fixed principle, which is probably one and the same, but disguised by combinations not yet discovered and analyzed. We shall endeavour to avoid either extreme of too much abstraction, or too extensive enumeration, and shall therefore divide earths into two classes, namely,
crystalline

crystalline and absorbent, which last we shall again subdivide into three, namely, calcareous, argillaceous, and gypseous earths.

Crystalline earth, which is also called vitrifiable and siliceous earth, is by far the most simple in its appearance, and known properties, of any other. All precious stones, flint, sand, gravel, and in general all minerals which have not a metallic appearance, and are sufficiently hard to give sparks with steel, are of this class, and may, from this last criterion, be easily distinguished. Crystalline earths, and even glass, if rubbed together, become ignited, for the instant, at the place of contact, and emit a peculiar smell, which is somewhat sulphureous. If this experiment be made in the dark, the crystal is luminous through its whole substance, which circumstance has been thought perplexing by an eminent chemist, who did not consider that it was no more than ought naturally to follow from the repeated reflections of the light from the internal surfaces.

Pure crystalline earth is insoluble in acids, and does not combine with water, even so much as to form a paste when finely powdered.

dered. It suffers no fusion nor alteration of weight by exposure to heat; but sands may be made to conglutinate a little by means of a violent fire: from which it seems, that their infusibility depends on our not being able to apply a sufficient degree of heat. It is called vitrifiable earth, because many specimens of it may be converted to glass, by the addition of a less quantity of fixed alkali than is required to effect the like with other earths.

The native masses of this earth affect a regular figure; especially such as are clear and transparent. These, if unbroken, are in general bounded by a number of plane surfaces, whose distances vary, but whose angles of inclination to each other are usually constant. Thus, rock crystal is commonly in the form of an irregular hexagonal prism, whose six plane sides make angles of 120° with the contiguous planes, and whose ends are terminated by one or more planes, which are usually inclined to the axis of the prism in an angle of about 40° .

The calces or earths of metals seem to be of this class, but altered by a remain-

ing portion of phlogiston, by means of which they are soluble in acids, and may be vitrified without addition of any other substance.

Absorbent earths are so termed from their property of imbibing water, with which they form either an intimate or a partial union. We shall proceed to describe these under the general heads of calcareous, argillaceous, and gypseous earths.

Calcareous, which are also called alkaline earths, are remarkable for the property of becoming caustic by means of fire. In fact, the heat decomposes them, and leaves the residue in that unsaturated state in which causticity consists. All native calcareous earths are sufficiently soft to receive impressions from the point of a knife, and if broken, the surface appears porous and granulated, somewhat like sugar. The opaque specimens are, limestone, several kinds of marble, chalk, the shells of fish, and other animal substances, when calcined after precipitation from an acid by fixed alkali. The transparent specimens are several heavy spars of a laminated texture; among which is
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the substance called island-crystal, well known for its peculiar quality of dividing the rays of light into two nearly equal parts, one of which is refracted in a manner not conformable to the general rules of optics ; whence it happens, that bodies seen through this crystal appear double. The stalactites, or stony isicles, which hang from the roofs of caverns, are also of this class.

Calcareous earths which have not yet been burned, are called mild. When exposed to a red heat for a considerable time, they lose about half their weight, and are converted into quick-lime. In their mild or saturated state, the quick-lime is combined with water, and a peculiar acid, which we shall have occasion to describe under the name of fixed air, both which are detached and driven off by the application of heat. Quick-lime, which is unmixed with other substances, may therefore be considered as pure calcareous earth.

The affinity between quick-lime and water is so great, that their union is attended with great heat. Quick-lime is actually dissolved in water, but the quantity required

required to saturate a given quantity of water is very small. Water thus impregnated has an acrid, alkaline taste, and is called lime-water.

Acids dissolve calcareous earths, and the combinations form various salts. If the calcareous earth be in a mild state, when immersed in the acid, the fixed air escapes in the form of bubbles, and the agitation of the fluid occasioned thereby is called effervescence: but quick-lime, or caustic calcareous earth, being already deprived of its fixed air, is incapable of effervescing.

If water be poured on a small quantity of quick-lime, it dissolves a small portion, and becomes lime-water. On the surface of this water is formed a scum or crust, which, breaking, falls to the bottom: a new scum is then formed, which likewise precipitates; and this continues for a certain time, at the end of which, the water becomes pure and insipid, and the earth at the bottom is in a mild state, and no longer soluble in water.

To explain this, it is to be observed, that the quick-lime, which is in solution near the surface of the water, attracts fixed air

from the atmosphere, and becomes mild; and as mild calcareous earth is insoluble in water, it forms a scum which continually increases, till it is too gross to be supported at the surface, but breaks and falls down: the water still retains its saturation, by dissolving fresh quantities of the quick-lime at the bottom; the scum, therefore, continues to be formed, and to be precipitated as long as any quick-lime remains undissolved; at the end of which time the quick-lime, being all rendered mild by the continued addition of fixed air, the water is left pure and insipid. The precipitate will effervesce with acids, and is in the same state it was before it was burned.

Quick-lime possesses many of the properties of fixed alkalis, though not so strongly. It turns blue vegetable infusions to green, and unites with sulphur, forming a compound, soluble in water like liver of sulphur. It has likewise some action upon oils and spirits of wine. But it is not fusible without the addition of an alkali, though calcareous spars and stalaclites in a very fierce heat shew signs of a beginning fusion.

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Yet it is very remarkable, that these substances, though so refractory when alone, are nevertheless capable of assisting the fusion and vitrification of several other matters, as sands and clays. This is a very difficult phenomenon to account for.

The earth called magnesia may be classed among calcareous earths, though its properties differ from those of the latter in several respects; particularly in that of being not at all soluble in water.

Calcareous earths in fine powder form a paste with water, which is not ductile, and dries very quickly. This is called mortar, and is durable in proportion as its causticity is more perfect. In order to give solidity to mortar, and render it more fit for the purposes of building, it is usual to incorporate a quantity of sand with the mass.

The second class of absorbent earths is the argillaceous. Its distinguishing property is that of forming a very tenacious and ductile paste with water, which may be moulded into vessels that preserve their form, and if gradually dried and exposed to a strong heat, bakes into a kind of stone called brick.

On this property of clays is founded the very useful and elegant art of pottery.

Boles, fuller's-earth, tile-earth, brick-earth, potter's-clay, pipe-clay, porcelain-clay, &c. are specimens of argillaceous earth; but the purest earth of this class is that which is obtained from alum. Alum is a combination of the vitriolic acid with argillaceous earth: now, if fixed alkali be added to a solution of alum, it combines with the acid, and the earth is precipitated in the form of a very fine white powder.

Argillaceous earths mix very intimately with water, but are not dissolved by it; for they subside after being some time at rest, but they are soluble in acids, particularly the vitriolic, with which they form alum, as we have already observed.

All clays which have been yet examined are found to contain vitriolic acid: and clay is found to obtain the properties of vitrifiable earth, by being well baked. In this last state it is as hard as flint, and strikes fire with steel; and if it be pulverized, it is found to possess no longer the property of combining with water or acids, but perfectly resembles fine sand.

sand. For these reasons clay is considered by many to be vitrifiable earth, altered by a combination with the vitriolic acid.

Pure clay resists the most violent fire without fusing, even though in contact with vitrified matters. Melting-pots or crucibles are made of clay mixed with gross powder of broken earthen-ware. The vessels which contain the melted matter in glass-houses will sometimes last a year, but they grow gradually thinner, probably from the action of their contents.

The last general head of absorbent earths are gypsums, or plaster-earths. The peculiar and leading property of gypsum is, that if calcined and mixed with water to the consistence of thick cream, it suddenly coagulates, and becomes considerably hard. From this circumstance it is exceedingly useful for casting small statues, or obtaining very accurate copies of bas-reliefs, as we see practised every day. In commerce it is called plaster of Paris.

Native gypsum is a soft, friable matter, and is found in large quantities in many parts of the earth. There are large mountains and hills in the neighbourhood of Paris, which are formed of this substance. It is always

crystallized, or regularly disposed, but its forms are various. It is found in the form of large, transparent, shining thin plates, applied to each other so exactly, that they constitute masses as transparent as crystal. These are called *lapis specularis* by naturalists, from their large shining surfaces, like those of mirrors. Again, large quantities of gypsum are found crystallized in striæ, or threads, applied longitudinally to each other. This is called striated gypsum. And lastly; a very large quantity of gypsum is found in small irregular crystals, adhering to each other, forming semi-transparent stones, called gypseous alabaster, which are very beautiful when white and pure. Notwithstanding this diversity of external appearance, these gypsums are perfectly similar as to their chemical properties.

When exposed to a considerable heat they lose their transparency, and the adhesion of their parts is almost entirely destroyed, so that they may easily be crumbled into a fine white powder. If they be mixed with water in this state, they soon acquire that solidity and consistence which we have already mentioned as their distinguishing characteristic.

Gypsum

Gypsum has a considerable resemblance to calcareous earth. It is soluble in water, to which it communicates the alkaline property of changing the blue infusions of vegetables to green, as quicklime also does. It likewise has some action upon sulphur, with which it forms a hepar or liver. But it does not dissolve or effervesce with acids. In fact, if a sufficient quantity of acid be poured upon gypsum, a kind of solution may be made; but the gypsum does not properly combine with the acid; for it may be recovered in its original state merely by crystallization.

The heat which is commonly produced in furnaces is insufficient to melt gypseous earths without addition; but by a more violent and long-continued heat it may be fused. It may be melted by the solar rays collected by a concave mirror, and a very small piece may be made to melt and run into a hard white globe, by means of an enameller's lamp. But in this last experiment it may be supposed to receive phlogiston from the flame.

If gypsum be boiled with a mild fixed vegetable alkali, the water is found to contain vitriolated tartar, and the earth at the bottom

of the vessel becomes calcareous earth. We must observe, that vitriolated tartar is the name of a salt composed of the vitriolic acid, and fixed vegetable alkali. The explanation of these appearances is evidently this; two decompositions and two new combinations take place by means of what chemists call a double affinity: the fixed vegetable alkali combines with vitriolic acid, which it must obtain from the gypsum, and forms vitriolated tartar; while the fixed air quits the mild alkali, and combines with the earth of the gypsum, forming mild calcareous earth, which may be converted into quicklime by burning. From this it is obvious, that the component parts of gypsum are calcareous earth, and the vitriolic acid.

If gypsum be distilled with powder of charcoal, a volatile sulphureous acid and true sulphur are obtained. These being likewise the produce of charcoal, or other phlogistic matters treated with the vitriolic acid, are an additional confirmation that it exists in gypsum. But the existence of the two principles in gypsum is placed beyond doubt, by the artificial production of this substance, which is
effected

effected by saturating the acid of vitriol with calcareous earth. This combination is called selenites.

From this account we may explain all the properties of gypsum. As it is properly a salt, it wants hardness, is transparent, soluble in water, and capable of crystallization. It cannot be combined with any acid, because it is naturally saturated with the vitriolic acid. Its calcination, by which the adhesion of its parts is destroyed, consists in the expulsion of the water which entered into its crystallization: and when it is again combined with water, it crystallizes, or grows solid, very suddenly and confusedly, because it requires a very great quantity of water to hold it in solution. And the properties of quicklime, which gypsum obtains in a small degree, may be attributed to the subtraction of a part of the vitriolic acid, which combining with the phlogiston of the fuel, becomes sulphur, and is burnt; by which means a part of the calcareous base of the gypsum is left uncombined: and gypsum is accordingly observed to emit a small flame when calcined in an open fire, or heated by a lamp and blow-pipe.

C H A P. V.

Of Acids.

THE affinities of bodies to each other are so numerous, that we find no bodies in nature but are in a state of composition. Water is in general purified by distillation, earth by calcining, and acids and alkalis are never met with pure, but must be obtained by chemical methods. We shall here proceed to describe the several acids, and the substances from which they are procured.

Acids are obtained from the mineral, vegetable, and animal kingdoms, and are accordingly denominated. Mineral acids are, 1. The vitriolic acid. 2. Nitrous acid. 3. Marine acid. 4. Acid of borax. Vegetable acids are, 1. Acetous acid. 2. Vinous acid, or acid of tartar. 3. Essential acid of vegetables, as lemons, &c. 4. Acid obtained by distillation of vegetables. Animal acids are, 1. Phosphoric acid. 2. Acid obtained by distillation from ants. 3. And the poisons of ants,

ants, bees, wasps, and other venomous animals are probably acids. Perhaps the number of acids may be much larger; or perhaps some of these may be only modifications of other primary acids; or they may perhaps be all modifications of the one primary acid; namely, that of vitriol, as the great Stahl conjectures.

The vitriolic acid, improperly called oil of vitriol, is obtained chiefly from sulphur, which is sometimes found native, but much oftener extracted from a mineral known by the name of pyrites. Pyrites is a hard substance, capable of giving sparks with a steel, from whence it has its name. It has almost always a metallic, yellowish or white appearance, and is often very regularly shaped; but the forms are so various, that it is impossible to enumerate them. These bodies are ores of copper, arsenic or iron; but the proportion of sulphur is very great to that of the metal. The most common kind are those which contain iron, and are generally of an irregular spherical or cylindrical figure, and when broken appear to be internally composed of needles or radii, which unite in the center or in the axis of the solid.

These

These pyrites, which are found to consist of much sulphur, some iron, and a small quantity of argillaceous earth, are decomposed by exposure to the air. For the phlogiston of the sulphur has a tendency to unite with the air, and the vitriolic acid of the sulphur tends to combine with the iron. These two actions gradually decompose the sulphur, especially if a proper degree of moisture be added; for the vitriolic acid dissolves iron more readily when somewhat diluted. Thus the phlogiston flies off into the air, and the acid, combining with the iron, forms a salt, called vitriol, the whole mass falling into an efflorescence, or powder. This decomposition, and new combination, is attended with heat; and in some circumstances, chiefly depending on the quantity of the pyrites and their moisture, actual fire is produced. Combustion, depending on the rapid combination of phlogiston with pure air, as has been already observed, it is not to be wondered that a too copious disengagement of that principle should produce ignition in the present instance.

The efflorescence being dissolved in water, with the addition of pieces of old iron, to
combine

combine with any part of the acid, which might be in a disengaged state, produces crystals of vitriol, by the evaporation of the water. This vitriol is of use in the arts, and was formerly the substance from which the vitriolic acid was procured. For this purpose this salt was deprived of part of the water of its crystallization, by means of fire, which changes it into a red substance, called colcothar. The colcothar being submitted to distillation, with a strong heat, affords a sulphureous acid, which was afterwards rectified by a second distillation; a volatile, weak sulphureous acid came over into the receiver, which was called spirit of vitriol; and the fixed, heavy, and concentrated acid, which remained in the retort, was called oil of vitriol, and is the pure vitriolic acid.

But this troublesome operation is now avoided, and the vitriolic acid is obtained from pyrites, by a much shorter and cheaper process. By a strong heat sulphur is sublimed in close vessels, from pyrites not yet fallen into efflorescence, and from the sulphur, by burning, is obtained the vitriolic acid. Every one knows what a strong and suffocating vapor exhales

exhales from burning sulphur; but the chief difficulty consists in condensing it. In great works, leaden vessels are used, called houses, of a prismical form, the bases of which are about six feet long and four broad, and their height about ten feet. The bottom of each of these vessels is covered with a small quantity of water, to assist the condensation of the vapor. Above the water is placed a small vessel, capable of containing a few pounds of sulphur, to which a small portion of nitre is added; because the nitre in burning actually produces a quantity of pure air, by means of which the combustion of the sulphur may be continued a longer time without access of fresh air. The vessels are to be filled with the vapor of hot water, and their sides wetted with the condensed steam: then the sulphur is to be kindled by touching it with a red hot iron: the vapor of the burning sulphur rises slowly; and when it has risen as high as the mouth of the great vessel, this must be stopped, or very nearly stopped, that the vapor may be confined. The sulphur continues to burn till the air contained within the vessel and the nitre be no longer capable of maintaining

taining the combustion. The vapor remains a considerable time before it be intirely condensed, notwithstanding that this condensation is facilitated by the water in the vessel, and especially by the steam of water with which the vessel was previously filled. When all the vapor of the sulphureous acid is at last condensed, the sulphur is to be again kindled, and more added, if necessary, and the process repeated as before. When a sufficient quantity of acid is collected, it is to be taken out of the vessel; and after it has lost its sulphureous or volatile quality by exposure to air, it is concentrated, by distilling off the superfluous water. This is the vitriolic acid; and its fixity is so great, that it cannot be made to boil by a heat less than ignition. The last portions of water are retained so strongly, that they cannot be driven off but by a strong and continued heat; and it may be so far dephlegmated as to appear in a concrete state in the usual temperature of the atmosphere.

The rationale of all this is obvious. The combustion causes the phlogiston of the sulphur to unite with the air, and raises the vi-

triolic acid, which is still so volatile, on account of a remaining portion of phlogiston, as not to be easily condensed, without combining it with a more fixed substance, as water. When the contained air is saturated with phlogiston, the combustion ceases, and the water becomes slightly acid by the condensed vapors of vitriolic acid, which acid is rendered more pure by exposure to the air with which its phlogiston combines.

The purest vitriolic acid is entirely free from smell or colour, and its specific gravity, when well concentrated, is to that of water as 17 to 8. It possesses all the characteristic properties of acids more strongly than any other acid, and its affinity with water is such, that it unites with it with an astonishing activity and impetuosity; and the heat resulting from the re-action of these two cold liquors is so great, that in an instant it equals, and even much surpasses, that of boiling water.

We have already mentioned the production of sulphur, by treating the vitriolic acid with any inflammable substance, and have applied the fact to prove that phlogiston is similar to itself in all bodies which contain it. It is not therefore

therefore for the sake of making sulphur, which can be more conveniently procured from pyrites, but in order to establish this important truth, that the experiment is made. The chief circumstance to be attended to in the process is, that the vitriolic acid be very much concentrated, and the inflammable substance very dry: for, as the vitriolic acid has a very strong affinity to water, its tendency to combine with phlogiston must be weakened in proportion to the quantity of water which presents itself. If, therefore, the vitriolic acid in a fluid state, that is to say, combined only with water, be submitted to distillation together with oil of turpentine, or any inflammable substance containing water, the phlogiston is made to combine with the acid in that weak manner which constitutes sulphureous acid; which is so volatile that it cannot be condensed in the heat of the atmosphere, without presenting another more fixed substance to which it has an affinity, as we have already observed. But towards the end of the operation, when the residue of the oil is reduced to the form of a coal, and the vitri-

olic acid exceedingly concentrated, the combination forms true sulphur, which sublimes to the neck of the retort.

This method is simple and obvious, but is attended with some danger of bursting the vessels, by a too rapid conversion of the acid into vapor. The more studied method of Stahl is to be preferred, which is this: vitriolic acid being combined and saturated with fixed vegetable alkali, forms a salt called vitriolated tartar: to this salt is added an equal quantity of fixed alkali, together with half the quantity of powdered charcoal. The whole must be put into a crucible, and well mixed together; and the crucible, being covered, is to be exposed to a strong heat suddenly applied, and continued a very short time. The melted mixture being poured out on a stone, previously greased, coagulates by cold, and is found not to differ from ordinary liver of sulphur, except in the admixture and solution of a small portion of charcoal. If this liver of sulphur be dissolved in water, and an acid added, a precipitate falls down, which is sulphur.

In the table at the end of chap. 3. alkali and sulphur are said to produce liver of sulphur. In order that the just mentioned process may be more easily understood, it will be proper first to describe this substance. If equal parts of fixed alkali and sulphur be melted together, a compound is formed of a brick-dust color, which is from thence called liver of sulphur. This combination may also be formed by boiling these two substances in water, but the method is less advantageous, and therefore less used than the other. In this compound the alkali is united with the acid, but much less strongly than if the acid were not at the same time combined with the phlogiston. The combination between the acid and the phlogiston is also rendered less strong and perfect; for the power of saturation in the acid, being probably limited, cannot be applied to the alkali without either letting go, or at least retaining less forcibly the phlogiston. From this it follows, that the phlogistic and alkaline properties must be the most perspicuous in the composition. The phlogiston being weakly attached, is continually escaping and combining with the air;

and the alkali, not having its whole tendency to union saturated, renders the compound soluble in water, and even attracts the vapors from the atmosphere, by which it deliquesces, or becomes moist. And therefore liver of sulphur exposed to the air continually emits phlogistic vapors of a faint and putrid smell, by which the air is vitiated, and at the same time it grows more and more moist, till at length nothing remains but a deliquium containing vitriolated tartar, that is to say, vitriolic acid combined with fixed alkali.

Pure vitriolic acid has so great an affinity with fixed alkali, that it dislodges every other acid with which the alkali may be united, and combines with it itself. But in fresh liver of sulphur, the vitriolic acid, being already combined with the phlogiston, is weakly attached to the alkali, as has been said, and for that reason may be easily separated from it even by the weakest acid. Thus, liver of sulphur being dissolved in water, the alkali may be detached by pouring in any other acid, with which it unites: and consequently the vitriolic acid and phlogiston being left at liberty to exert their whole mutual action, cohere strongly,

strongly, and form again the compound sulphur, which not being soluble in water, immediately precipitates in the form of powder. A strong phlogistic vapor escapes during this process; from which we may conjecture, that a part of the vitriolic acid of the sulphur is detached in a volatile form during the fusion by which the liver is made, and that the remaining phlogiston of that part combines with the alkali: so that when the decomposition takes place, the vitriolic acid, uniting strongly with its proper quantity of phlogiston, and the alkali uniting with the superfused acid, that portion of phlogiston which was united with the alkali is left in a disengaged state, and readily combines with the air. That these vapors are phlogiston, appears from their producing the same diminution and noxious qualities in the air, and even from the changes they produce in metallic substances, the calces of some of which are even revived by them.

These things being duly considered and attended to, there will be no difficulty in accounting for every thing that happens in Stahl's process for making sulphur. The acid in vitriolated tartar is in a state of much concentration,

tration, and the superaddition of fixed alkali tends to increase that concentration, by attracting the water which entered into the crystals of the salt. In this state, charcoal, that is to say, phlogiston combined with an earthy base, is presented. The vitriolic acid has a greater affinity to the phlogiston than to any of the other principles which enter into this compound, but, for the reasons mentioned in the first and second chapters of this section, the affinities are not exerted without heat. Heat therefore being applied, the principles of the whole mass arrange themselves so as to satisfy, as much as possible, their several elective attractions; the vitriolic acid forms sulphur with the phlogiston, and the alkali holds that sulphur in solution, forming the liver, while the charcoal is in part decomposed, in part dissolved, and in part merely mixed with the compound.

The next mineral acid is that of nitre; but whether the nitrous acid be really a mineral substance or no, is not easy to determine. It is obtained from nitre, a salt whose original is very dubious, but which is, for the most part, obtained by an artificial combination of an alkali with the saline part of animal or vegetable

vegetable substances, which have completely undergone the putrefactive fermentation. We shall be more particular when we come to speak of this salt, which is found to consist of a fixed alkali, combined with a peculiar acid. This acid is called the nitrous acid.

To detach the acid of nitre, which is usually called spirit of nitre, from its alkaline base, the acid of vitriol is made use of, on account of its stronger affinity with the alkali. For this purpose martial vitriol, deprived of its superabundant water by calcination, or else the pure concentrated vitriolic acid is added to nitre, and the whole submitted to distillation in a reverberatory furnace. In either case the vitriolic acid combines with the alkali of the nitre, and forms vitriolated tartar, while the nitrous acid, being disengaged, passes over in the form of red fumes into the receiver, in which it becomes condensed. If the calcined vitriol be made use of in this process, the nitrous acid is more red and smoking than in the latter case; which circumstance is probably owing to the phlogiston, which is one of the principles of the iron. These methods are usually adopted by chemists, but the ni-

trous acid, called aqua fortis, which is used in the arts, is obtained from nitre mixed with clay, previously well dried. The decomposition takes place as before, and is in general attributed to the vitriolic acid, which, as we have already observed, is found in all clays. But if we consider that the quantity of vitriolated tartar found in the residuum is very small, and that the nitrous acid may be distilled from nitre mixed with clay already baked, as broken tobacco-pipes, or even with pure vitrifiable sand, we have reason to conclude that these intermediate substances are chiefly useful, by preventing the nitre from melting into a coagulum, by which means a more extensive surface is left for the escape of the nitrous acid, which comes over principally because it is much more volatile than the alkali with which it was combined.

In the distillation of nitrous acid, care must be taken to apply the heat very gradually, as a neglect of this precaution may be attended with dangerous explosions.

Nitrous acid, as it is usually met with, is of a yellow straw color, and continually emits vapors of the same colour, and of a peculiar suffocating

suffocating smell. But this color seems to be accidental, and to depend upon some combination of phlogiston, with the mode of which we are unacquainted; for it may be deprived of it by a slight degree of heat without affecting its other properties. This acid is lighter than the vitriolic, and, when in the utmost concentration that can be obtained by ordinary means, is to the weight of water as 19 to 12. It unites with water with a considerable heat and ebullition; and while they are mixing, the mass assumes a blue or deep green color. If exposed to the air, it attracts the humidity from thence, but not so strongly as the vitriolic acid.

All the distinctive and general characters of acids are found in the acid of nitre. Many chemists are of opinion that it is no more than the vitriolic acid combined with phlogiston in the process of putrefaction, by which nitre is obtained: and they support their opinion by observing, that the volatile sulphureous acid, which is evidently nothing more than the vitriolic acid combined with phlogiston, resembles the nitrous acid, and approaches to it in those particulars in which it differs

differs from the vitriolic. It is even asserted, that the conversion of the vitriolic into the nitrous and marine acids has been effected; but the assertion has not yet been proved.

Nitrous acid is one of the most powerful menstruums in chemistry, not that it is the strongest acid, for in strength it is inferior to vitriolic acid, and even in certain circumstances to marine acid; but on account of the facility, the quickness and the activity with which it dissolves most substances.

The affinity of nitrous acid to phlogiston is very great. In fact, phlogiston seems to be the intermediate substance by means of which it holds most bodies in solution. If to nitrous acid, which is saturated, with iron for example, a fresh portion of iron be added, it will dissolve that likewise, and let fall a precipitate at the same time, which is a true calx of iron. Now, whether the precipitate be the iron last added, which is calcined by the subtraction of its phlogiston, or whether this last be dissolved, and a part of the former precipitated, the result is the same, namely, that the affinity of nitrous acid to iron depends on the phlogiston of the latter. And
tin,

tin, which has the least attachment to its phlogiston of any metal, as appears by the ease with which it is calcined by fire, is very imperfectly dissolved by this menstruum; by far the greater part being calcined and precipitated without addition of any other substance.

We have seen in many instances that heat is produced by the concurrence, and, perhaps, collision, of two substances, whose mutual affinity is very strong: and we have observed, that the mutual affinity of phlogiston and pure air is very probably the cause of that increase and continuance of heat which is seen in bodies which are decomposed by the act of combustion. From every experiment there is reason to conclude, that the affinity between the nitrous acid and phlogiston is very great: and from very modern experiments it has been discovered, that this acid is the principal element which enters into the composition of pure air. By the help of these considerations and facts, we may venture to give a conjectural account of the strong and surprising combustion which is produced by

the application of substances containing phlogiston to the acid of nitre.

Concentrated nitrous acid being poured on any kind of oil produces great heat and effervescence, and in proper circumstances even accension. Oil of turpentine, of saffrafras, or of guyac, and in general any thick oil, into the composition of which little water enters, may be inflamed by the simple affusion of the acid. But the success of the experiment is much more certain, and may even be obtained with all other oils, if the nitrous acid be previously mixed with the vitriolic. The oil is first put into the vessel, in which the inflammation is intended to be made. Then the vessel containing the acid is to be tied to the end of a long pole, that the operator may not be hurt by the burning matter, which sometimes is thrown to a considerable distance on all sides. One-half or two-thirds of the acid is poured at once. A considerable ebullition is excited; the oil becomes black, thick, and sometimes inflames. But if it does not take fire in four or five seconds, the remainder of the acid must be poured on the part which
appears

appears thickest and driest, and then the inflammation of the mixture seldom or ever fails to take place.

In most chemical experiments, and particularly in this, the event is more certain when large quantities of the materials are used. Less than an ounce of each ought not to be used; but when a pound of strong nitrous acid is poured on an equal quantity of oil of turpentine, the effect is grand and astonishing. A thick column of flame and smoke, of above twenty feet in height, is instantaneously produced.

Does not this remarkable phenomenon depend immediately on the strong affinity between the nitrous acid and the phlogiston of the oil? In order that this affinity may exert itself as much as possible, it is necessary that both substances should be in the most uncombined state. The oil should contain very little water, and the acid must be very much concentrated. The addition of vitriolic acid to the acid of nitre increases this concentration, by subtraction of part of its water, to which the former has a greater affinity; and it may likewise tend to dephlegmate the oil
at

at the time of affusion. And since the concurrence of two bodies which strongly attract each other, is known to produce heat; the degree of that heat will depend on the strength of the affinity. If that be sufficiently great, accension may be actually produced, and the bodies in the instant of combustion may be volatilized and dispersed on all sides in a state of ignited vapor. Such is probably the case in the instance before us.

The third mineral acid is the marine, or muriatic acid, called also spirit of salt. It is obtained from common salt, and derives its names from thence. If the vitriolic acid be added to common salt, the marine acid immediately rises in white fumes, which are not easily condensed. For this reason, in distilling spirit of salt, a retort is used which differs from the common sort, in having a tubular opening, into which vitriolic acid, equal to one-third of the weight of the salt, may be poured at several times; and because of the difficulty of condensing the vapors, it is usual to dilute the vitriolic with water; so that the vapors of the water, passing over into the receiver together with the acid, assist the

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the condensation, upon the principle already explained, in speaking of the vapors of sulphur. But in common practice dried clay to the quantity of about twice the weight of the salt is used, instead of vitriolic acid. After the distillation, a salt is found in the retort, called Glauber's salt, which differs from vitriolated tartar in its base: for the base of common salt is the fixed fossile alkali, and differs in several particulars from the fixed vegetable alkali, which is the base of common nitre.

The marine acid is generally of a light yellow, and emits white and suffocating fumes, which are not visible, except in the open air. There is reason to believe that its colour is accidental, and that it ought to be clear and transparent when pure. Being more volatile than either the vitriolic or nitrous acids, it cannot be concentrated near so much; and its affinity with phlogiston is so weak, that we are not assured that it can at all be combined with it, unless by the help of some intermediate substance. It therefore in general dissolves metallic substances less, but their calces more readily than other acids: and from this property it adheres to, and precipitates
with

with the calces of metals, which are held in solution by the vitriolic, or nitrous acids, and forms marine salts with metallic bases. By this means it may be made to unite with several metals with which it was incapable of forming any union while in their metallic or phlogistic state.

Yet by an artful management of this acid with ardent spirits, a very volatile and inflammable fluid may be obtained by distillation, called ether. There are also vitriolic and nitrous ethers, though the vitriolic is the only one found in the shops. This combination seems to be an intermediate substance between ardent spirit and oil, and partakes of the properties of both.

The marine acid possesses all the common properties of acids.

The acid of borax is better known by the name of sedative salt. It is obtained from borax, which is a saline substance, brought from the East-Indies, whose origin is unknown to us. If borax be dissolved in hot water, and the solution filtered, and any one of the three mineral acids be added, by a little at a time, till the liquor be saturated, and
even

even have a slight excess of acid; a great number of small shining laminated crystals will be formed in the liquor when cool. These must be washed with a little very cold water, and are the sedative salt. The remaining liquor of the solution is found to contain a salt exactly the same as would have been produced by the combination of the acid made use of with mineral alkali. If the vitriolic acid be used, it contains Glauber's salt, if the nitrous acid, quadrangular nitre, and if the marine acid, common salt. And, on the other hand, if sedative salt be added to the mineral or fixed fossile alkali, borax is produced.

Sedative salt therefore acts as an acid in the combination of borax by neutralizing the alkali; but it is deficient in most of the other properties of acids. It is a concrete substance, difficultly soluble in water, and may be fused into a kind of glass, without altering its properties: and it has neither the acid taste nor the property of changing blue vegetable infusions to red. Many chemists believe it to be a combination of the vitriolic acid, with a vitrifiable earth; but as the attempts to ana-

lyze it have not hitherto been successful, we have chosen to arrange it in this place. Yet, nevertheless, when we speak of mineral acids we would be understood to conform to the usual acceptation, and to mean the vitriolic, nitrous, and marine acids.

The acetous acid is produced by a second fermentation from vegetable substances, which have already undergone the vinous or spirituous fermentation. This second fermentation is attended with heat, and requires peculiar management. The chief circumstance to be attended to is to prevent the spirituous part of the wine from escaping; for the greater the quantity of ardent spirits, or, in other words, the stronger the wine, the more brisk and acid the vinegar. This acid is combined with much water, and oily or mucilaginous matter, so that it cannot be obtained in a state of such concentration as the mineral acids. If vinegar be distilled, a purer acid may be obtained, but weaker: if it be exposed to freeze, and the ice taken away, the remainder is concentrated in a considerable degree. But the highest degree of concentration of this acid is obtained by combining it with alkalis, earths,
or

or metals, and afterwards decomposing by means of fire. Thus, verdigrise, which is copper corroded by the acid of grapes, being dissolved in hot distilled vinegar, forms by evaporation crystals of a salt which is improperly called distilled verdigrise: if this salt be submitted to distillation, the water which entered into the formation of the crystals comes first over; and afterwards, when the retort begins to be red hot, the acid passes over, partly in white clouds, and partly in drops. This strong acid has a very pungent and suffocating smell, and is called radical vinegar, or, improperly, spirit of Venus.

The acetous acid has all the general properties of acids. Radical vinegar, when well concentrated, easily crystallizes, or takes a solid form without addition. It has, besides, the remarkable property of burning entirely away, like ardent spirits, if heated in an open pan and set on fire. This, added to the observations which are suggested by the mode of its formation, tends to prove that ardent spirit enters into the composition of vinegar.

Vinous acid, or tartar, seems to be nothing else than the acetous acid combined with a portion of fixed vegetable alkali. It is probable that all wines undergo an insensible fermentation for a very long time after the sensible spirituous fermentation has ceased; whence they are altered and meliorated by age. Whether this be a beginning acetous fermentation, which is never completed for want of air, or whether it be something totally different, cannot be determined without express observation and experiment; but it is during this process, that a concrete saline oleaginous encrustation is formed on the inside of the cask. This matter exhibits all the signs of the presence of an acid, and is called tartar. Tartar, being dissolved in hot water and filtrated, takes the form of crystals by cold; which crystals, being farther depurated by boiling in water in which clay is diffused, are at length deprived of all their oleaginous matter, and partly by cooling and partly by evaporation, are again crystallized. In this last form they are usually called cream of tartar.

In order to discover whether this purified tartar, or cream of tartar, be a simple acid or a compound salt, it is dissolved in water, and the solution rendered neutral, that is to say, neither acid nor alkaline, by adding some fixed vegetable alkali. The salt produced by evaporation and cooling, is called soluble tartar. Again, to a solution of cream of tartar is added mild calcareous earth, till the acidity is destroyed, and no more effervescence produced: a copious white sediment falls to the bottom, and the liquor is found to contain soluble tartar exactly as before. Lastly, if diluted vitriolic acid be poured on the white sediment, it will become a gypsum, or vitriolic salt with basis of calcareous earth, and the liquor will contain an acid, to which, if fixed vegetable alkali be added, it will, by crystallization become cream of tartar, or, if the saturation was complete, soluble tartar.

It is not difficult to explain this. If cream of tartar be a simple acid, the soluble tartar produced in the first instance must be a combination of this acid with vegetable alkali. But, in the second experiment,

we have a proof that it is not simple ; for instead of forming a simple combination with the calcareous earth, two distinct substances are produced, namely, a white precipitate, and a soluble tartar in the liquor. The precipitate is found to be a salt ; for upon combining the vitriolic acid with its calcareous base, an acid which it must have acquired from the tartar is detached. And this acid, being combined with vegetable alkali, and producing either cream of tartar, or soluble tartar, according to the proportions, evidently shews the component principles of those salts. Tartar then is a combination of an acid, not yet sufficiently examined, with the fixed vegetable alkali, but in which there is a superabundance of acid. If a sufficient quantity of alkali be added to engage the superfluous acid, a neutral salt is produced, or if that superfluous acid be combined with calcareous earth, and precipitated in the form of a difficultly soluble salt, the remainder of the tartar, being deprived of its superabundant acid, must be converted into the same neutral salt, or soluble tartar,

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The existence of vegetable alkali as a principle in tartar, is likewise proved, by treating it with the mineral acids. For by combining with its base, they severally form precisely the same salts as would have been produced by their direct combination with fixed vegetable alkali.

The essential salts of vegetables, and the acids which enter into their composition, have not yet been enough enquired into. An experimental analysis of these substances cannot fail to furnish very interesting and valuable knowledge. The great difficulty in this research consists in depriving the salts of that mucilage and saponaceous matter, which not only prevents their crystallizing in water, but likewise makes them more subject to alteration when submitted to fire. The acid obtained from sugar, by treating it with the nitrous acid, is found to be much more powerful, with respect to the chemical affinities, than the acetous acid.

We know very little concerning the acids which are procured from vegetable, or even animal matters, by distillation : neither have

those substances, which are remarkable as poisons in venomous animals, been examined with any degree of accuracy.

The acid of phosphorus is usually termed an animal acid. Phosphorus may be obtained from farinaceous grains, and therefore its origin is probably in the vegetable kingdom; but by far the greatest quantity is found in urine. If urine be evaporated, so as to leave but one third of the original quantity, the saline matters it contains begin to crystallize as it cools. These salts, except one, are nothing more than what has been received with the aliments, and have passed through the animal unaltered. One of the first that crystallizes is the salt we have excepted. It is called fusible salt, and consists of the phosphoric acid combined with volatile alkali. The volatile alkali may be driven off by heat; but the acid is so fixed, that it may not only be deprived of the water, by which it was kept in a fluid state, but also when thus dried, may be rendered red hot without subliming, and may be thereby changed into a solid

solid and transparent matter, which has the appearance of glass.

This acid has all the general properties of acids. While hot it corrodes glass. But its remarkable property is that by combination with phlogiston, it forms a sulphur which is inflammable with a much less degree of heat than the common vitriolic sulphur. These two substances have the peculiar property of being decomposed by two different kinds of combustion. If the end of an iron poker be heated red hot, there will be a certain part of it, at a little distance from the ignited end, which will be just hot enough to melt brimstone, and cause it to smoke, without bursting into its usual blue flame. Yet this apparent smoke is an actual luminous flame, as may be proved by repeating the experiment in the dark; and if the ignited part of the iron be touched with the sulphur, the strong and ardent flame may be produced at the same time, by which the difference may more sensibly be observed. The faint, or, as it may be termed, the phosphoreal flame, may be produced in common sulphur by an iron not much hotter than the
hand

hand can bear, and is incapable of setting fire to the lightest flax. It may even be suffered against the palm of the hand without inconvenience; in which case, the flame is deflected much in the same manner as the flame of a candle against the ceiling of a room.

Phosphorus is so inflammable, that a very slight friction is sufficient to cause the most violent combustion. The phosphoreal flame is produced in the open air by a heat considerably less than that of freezing: consequently it always smokes, and is continually decomposing, by the escape of its phlogiston, unless this slow combustion be prevented, by keeping it constantly immersed in water.

If urine be boiled to the consistence of an extract, and afterwards submitted to distillation, all the volatile products come over first, and at length, by a continuation of the utmost violence of fire, the phosphoric acid combines with the phlogiston of part of the coaly residue, and passes over in the form of luminous fumes, which, when condensed by water in the receiver, are the phosphorus.

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But this process is very tedious and laborious. It is therefore usual to make it by previously mixing a quantity of the extract of urine, with a quantity of plumbum corneum, and a little powdered charcoal, over the fire, till by evaporation the whole is converted into a black powder. Plumbum corneum is a saline combination of the marine acid with the calx of lead, and is perhaps of no use in this operation. This black powder is submitted to distillation by a gradual heat, and the fire is increased till the retort is red, and nothing comes over. The receiver is then changed, and a new one being adapted, half filled with water, the fire is raised till the retort is brought to a white heat. The phosphorus passes over in vapors, and manifests itself by the light which spreads through the inside of the receiver, and which issues through the little hole made in its body. When the operation is finished, the vessels are suffered to cool during forty-eight hours. At the bottom of the receiver is found a black coaly matter, which contains the phosphorus. A second distillation with a moderate heat rectifies this phosphorus:

water

water being put in the receiver, to prevent its burning as it comes over. The phosphorus in this last state, is of a pure yellow colour, and being almost as fusible as suet, is cast into sticks, by putting it with water into small glass tubes, which being immersed in warm water, the phosphorus melts, and runs into a body at the lower end.

C H A P. VI.

Of Alkalis.

ALKALIS are either fixed or volatile, and there are two kinds of fixed alkali, namely, vegetable and mineral, or, as some call it, fossil. The affinities of alkalis to acids are so great, that they are almost always found combined with them. Thus, the vegetable alkali is found combined with an acid in tartar, and in nitre, and the mineral alkali is the basis of sea-salt. The volatile alkali is usually combined with the marine acid, forming sal ammoniac.

The vegetable and mineral alkalis being exceedingly fixed, and in general combined with fixed acids, it is evident that they cannot be obtained alone by the common chemical methods. The acid of common salt, for example, cannot be made to quit its base of mineral alkali, but by combining that base with an acid, and to which it has a stronger affinity;

so that the alkali must always remain in a combined state. The only method of decomposing these salts, which are composed of an acid and an alkali, is that of rendering the acid volatile; but we are not well acquainted with the means of doing this. Thus, if common nitre be made red hot, and charcoal be added, the acid of the nitre combines with the phlogiston of the charcoal, and is dispersed by a rapid inflammation: and at length the vegetable alkali is left in an uncombined state. Vitriolic salts may likewise be decomposed upon this principle: but, the affinity of the marine acid with phlogiston is so small, that a similar process has not yet been contrived with sea-salt.

All the fixed alkali in commerce is produced by burning vegetable substances, and extracting the alkali from their ashes by means of water. It has been a matter of dispute, whether the fixed vegetable alkali be not formed by the combustion, or whether it pre-existed in the vegetable. Both opinions are partly true. For it is evident that fixed vegetable alkali is contained in
substances

substances which have never passed the fire, as in tartar or nitre; and it is likewise as clear, that concrete acids, as they are called, are almost entirely changed into alkali by incineration. If tartar be tied up in wet brown paper, and burnt, it is converted into an almost equal quantity of alkali of very considerable purity: and universally, those vegetables, which contain the most essential salt, furnish the greatest quantity of alkali by burning; but if, by decoction, or maceration in water, they be deprived of those acid juices, or if they be changed by putrefaction, very little alkali is obtained from them.

Fixed vegetable alkali is obtained in a pure state by one or more solutions in water, and a careful calcination. At every solution an earth is precipitated, and it is affirmed, that alkalis may be entirely decomposed by repeated solutions and calcination. The vegetable alkali resembles a white earthy substance, which may perhaps consist of broken small crystals, and is usually combined with fixed air; but it may be rendered more caustic and incapable of effervescence,

effervescence, by being treated with quicklime, which deprives it of the fixed air. If exposed to the open air it attracts moisture, increases in weight, and becomes fluid. The vegetable alkali obtained by burning tartar is called salt of tartar, and the fluid produced by its deliquescence, is improperly named oil of tartar per deliquium. Many other names have been given to this alkali, according to the mode of procuring it, as fixed-nitre, potash, &c. but these are all entirely of the same nature.

Mineral alkali is said to be found lying on the ground in the island of Teneriffe, and other places; but the only practical method of procuring it in great quantities is by the incineration of marine plants. These plants contain sea-salt, which probably furnishes the alkali, by a conversion similar to that produced in the burning of tartar. These ashes are known in commerce by the name of barrilla, or soda; and the alkali, when purified, is in the form of small transparent crystals. It is so far from imbibing the moisture of the atmosphere, that it even loses the water which entered into the composition of its crystals, and

and falls into a powder by exposure to the air. This weak affinity with water is one of the most distinctive circumstances between the mineral and the vegetable alkali. The mineral alkali has a great resemblance in all its properties to the vegetable alkali, but in general possesses them in a less degree. It cannot crystallize when deprived of the fixed air with which it is generally combined.

The use of the fixed alkali, both vegetable and mineral, is very great in the arts. It readily combines with all oils, especially when rendered caustic by boiling with quicklime, which absorbs its fixed air. This caustic solution or lixivium is called lye or soap-lee, and is converted into soap by the affusion of a proper quantity of oil, the whole being kept at a very gentle heat, till it is brought to a proper consistence, by the evaporation of the water. Soaps differ very much, according to the quality of the oil made use of. Alkaline lye is likewise much used in the art of dying.

The property of dissolving earths, and forming that most useful and beautiful composition, called glass, constitutes one of the prin-

cipal advantages we enjoy from alkalis. A great heat is necessary for this operation; for which purpose the melting-pots are placed in a large dome-furnace, in which the flame is continually reverberated on them, and is never suffered to go out. Common salt and nitre, being in part composed of alkali, may be offered as additional proofs of the benefits which arise to us by means of this substance.

The volatile alkali is procured by decomposition from all animal, and some vegetable, substances, and is likewise disengaged from these matters by putrefaction. It seems to be the fixed alkali, altered and volatilized by phlogiston.

There are many chemical processes in which volatile alkali is produced from substances, in which it did not exist before; yet, that it exists ready formed in animal substances, seems probable, because they all give out a smell of the volatile alkali when fixed alkali is applied to them. Thus, the fusible salt, which consists of the phosphoric acid united with volatile alkali, exists ready formed in urine, whether putrified or not, and the alkali may be disengaged by throwing in
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a sufficient quantity of fixed alkali. This, by its greater affinity, combines with the phosphoric acid, and the detachment of the volatile alkali is immediately perceived by a strong pungent smell. And this smell is as instantly destroyed, by throwing in an acid, which fixes the volatile alkali again, by combining with it, and forming a neutral salt. But there is no doubt but that in many instances volatile alkali is not merely disengaged, but produced by putrefaction.

The volatile alkali, which is met with in commerce, is obtained from sal ammoniac, which, as we have observed, is a combination of this alkali with the marine acid. Sal ammoniac is found ready sublimed in the neighbourhood of volcanos; but the quantity is too small to furnish the demands of artists. The great supply is from Egypt, where it is obtained by sublimation, in an impure state, from the foot of the dung of camels, which is the common fuel of that country. It is purified with us, by solution in water, filtration, and crystallization; and may be sublimed a second time, if thought necessary; for the union between the volatile alkali and marine

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acid

acid is such, that they cannot be separated by mere heat, without the help of an intermediate substance.

Volatile alkali may be procured from sal ammoniac by distillation, if a fixed substance be added, which can combine with the marine acid. Fixed alkali, calcareous earth, or metallic calces, may be employed for this purpose. But the volatile alkali cannot be procured in an absolutely detached state : it is always combined either with water or fixed air ; and if the intermediate substance be incapable of furnishing either of these, as is the case with fresh hot quicklime, the decomposition does not take place. This serves to account for a difficulty which has been started concerning these decompositions. The volatile alkali has, very nearly, if not quite, as great an affinity with its acid base as quick-lime, and a much greater than any metallic substance, as is evident by its precipitating them from their solutions : how then does it happen, that it is disengaged by these substances ? The answer is, that though the attraction between the volatile alkali and marine acid is so great, that instead of being separated, they are both sublimed together, yet, the addition of a
third

third fixed substance, which has an affinity with the marine acid, may so far weaken that attraction, as to render the separation by heat possible. Or, if this be not thought sufficient, the probability of a double affinity taking place in the present instance is very great. Mild calcareous earth, for example, is added to sal ammoniac, and the whole submitted to distillation. The calcareous earth attracts the marine acid of the sal ammoniac, which has therefore a tendency to be decomposed on that account: and the volatile alkali being attracted by the fixed air of the quicklime, combines less strongly with its base than before. If the sum of these two attractions be greater than that which unites the alkali with its acid, a decomposition must take place, though neither of them singly could have effected it. The volatile alkali will consequently pass over in a combined state with fixed air, and the marine acid will remain, forming a salt with the calcareous earth. A similar effect will follow if the calcareous earth be caustic, but containing water, as is the case with flaked lime, except that the volatile alkali will then be caustic, and in a fluid state.

And if lime, containing neither water nor fixed air, be used, no decomposition will take place. But after all, this subject has its difficulties.

Volatile alkali differs according to the substances from which it was procured : but these differences are owing to its not being sufficiently purified. But if it be formed into sal ammoniac, by applying the marine acid, and afterwards recovered, it is universally similar. There is therefore but one sort of volatile alkali.

All the common properties of alkalis are found in this substance, excepting such as depend upon fixity, which it wants. Its affinities are weaker than those of fixed alkali. If sal ammoniac be treated with nitre in a crucible, the nitre inflames and detonates to a certain degree. As the marine acid of sal ammoniac cannot be supposed to afford the phlogiston, it must be furnished by the volatile alkali. This is an additional cause for believing that the volatile alkali contains a greater quantity of phlogiston than the fixed alkali.

The volatile alkali is used as a stimulant in fainting fits. With particular management
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it may be formed into a saponaceous, compound with oil of amber, or other oils, which being diffused in ardent spirits, forms that milky liquor called eau de luce. This liquor, externally applied, is said to be a specific for the bite of vipers.

C H A P. VII.

Of compound Bodies ; and particularly those which are inflammable.

WE have finished our account of simple bodies, in which we have been under the necessity of frequently describing and adverting to the properties of the compounds which are produced by their respective combinations. This anticipation, which the nature of the subject rendered indispensable, will conduce much to the easy understanding of the nature of the substances we are about to treat of.

All bodies may be arranged under two general heads ; namely, inflammable and un-inflammable. The first class consists of such as possess the principle of inflammability to such

a degree, that they may be decomposed by the act of combustion. These are ardent spirit, ether, oils, resins, sulphurs, metals, coal, and have no general term by which they may be denoted. The latter class, consisting of combinations of water, earth, acids, and alkalis, and if they possess phlogiston, being united with it in such a manner as to be incombustible, may be properly enough denoted under the general name of salts.

Here it is to be noted, that we speak of bodies, which, though capable of chemical decomposition, are yet very simple. Even in these, the limits of the two classes approach by such insensible gradations, that it is difficult to draw the discriminating line: but in more compounded substances there is hardly any particular specimen which does not consist of inflammable parts united with others of a saline nature.

Ardent spirit, or, as it is usually called, spirit of wine, because it is obtained by means of the vinous fermentation, is unalterable by distillation, when it is sufficiently pure. It is very volatile and inflammable, and burns without producing any smoke or coal: if it
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be burned in a tubulated retort, to which a large receiver is adapted, the condensed vapors are found to be very pure water. It seems therefore proper to conclude, that spirit of wine is pure phlogiston, combined with water.

If ardent spirit be added to concentrated vitriolic acid, and the mixture gently shaken, they unite with a boiling heat. By a careful distillation, the first product which passes over is a very dephlegmated spirit of wine; next an exceeding volatile fluid, called ether, which runs in streaks down the sides of the receiver; and, lastly, an oil, improperly called sweet oil of vitriol. A resinous coal remains in the retort. The rising of the oil is perceived by the sulphureous smell which issues from the small hole in the receiver; at which time, in order to preserve the ether, the receiver is removed. The ether is afterwards separated from the spirit by a second distillation, with a very gentle heat, in which, on account of its greater volatility, it rises, and leaves the spirit in the retort.

Similar

Similar processes may be made by mixing spirit of wine with the other acids; but this is the easiest, and the most in use.

Oil is an inflammable substance, insoluble in water, which, [when burned, emits a flame, accompanied with smoke; and when distilled, leaves a residuum of coal. The first part of this definition distinguishes it from ardent spirit, which unites with water in all proportions; and the latter part indicates the difference between it and sulphur, which, though likewise insoluble in water, burns without either smoke or residuum. Oil is obtained from vegetables and animals, but never from substances which are indubitably mineral. Bitumens, as petroleum, amber, jet, asphaltum, and pit-coal, yield an oil; but there are many reasons to suspect that these matters have been produced in their present form by time, and the action of the mineral acids on bodies, which in some former ages have been in the state of vegetation or animalization. Oils are obtained from vegetables by expression or distillation with water. The first are called sweet oils, and the latter essen-
tial

flial oils. Sweet oils are usually in an uncombined state in the vessels of the plant they are expressed from; they have very little taste or smell; but essential oils are obtained by a decomposition of the vegetable substance, and have all the peculiar smell of the plant they come from. These latter are exceedingly sapid, and much more volatile than the other; and, in consequence of that volatility, are likewise more inflammable; for oils cannot be inflamed but in a state of evaporation. In animal substances there are likewise two kinds of oil, namely, the fat, which is contained in an uncombined state in certain detached vessels, and an oil which is obtained from that gelatinous substance, or jelly, of which the parts of animals are almost entirely formed. This last is a true animal oil.

All oils are volatile in a considerable degree. The least volatile oil may be raised by a heat much less than a red heat. They are entirely decomposed by combustion.

If oil be distilled without addition, an acid phlegm first rises, and afterwards the oil itself, accompanied by an acid, which becomes more and more strong, as the distillation advances.

A small

236. *Of the Nature of Spirit, Ether and Oil,*

A small quantity of fixed coal remains, which contains earth, phlogiston, and a minute portion of fixed alkali. If the oil be repeatedly distilled, the same products are obtained, and the oil becomes more thin and volatile at every distillation.

Concentrated acids in general combine with oils, and render them more thick, and approaching to the nature of resin. Great heat and blackness, attended with a strong sulphureous smell, is produced by the admixture of strong vitriolic acid and oil; and the admixture of the nitrous acid with oils produces even accension, as has been already remarked.

The variety of oleaginous substances, and their respective products, have not been sufficiently and accurately attended to. Much remains to be done; but that which has already been done would require too large a detail to be admitted in this place. We shall therefore only make a few general observations on the nature of the three substances just described.

In the distillation of ether, spirit of wine, which was shewn to consist of phlogiston and

water, is converted into an oil, and this oil leaves an earthy residuum. The residuum must then have come from the acid. It is therefore highly probable that oil is composed of water, phlogiston, and acid. Pure spirit is entirely soluble in water. Ether is partly so; and oil is totally insoluble. Ether then is a kind of intermediate substance, between spirit and oil; and in most of the properties by which it differs from spirit it approaches to oil. It gives a smoke, and leaves a slight residuum in burning, and has other oleaginous qualities; but, on the hand, it is volatile like spirit, and rises entire in distillation. The analysis of oils shews that they contain water, phlogiston, acid, earth, and a small proportion of alkali. They are decomposed by distillation. A part of the phlogiston is dissipated: hence water and acid appear in an uncombined state. The earth and alkali in the residue are probably part of the same acid, still more decomposed: this is rendered probable, by the formation of oil from ardent spirit, just mentioned, in which the acid furnished an earthy residuum. And the distilled oil, being deprived of part of its acid, becomes

becomes more volatile and attenuated; that is to say, it approaches to the nature of spirit. In farther confirmation of this, we find that stiff and concrete oils, as suet, and wax, afford a greater portion of acid than thin ones; and thin oils may be rendered thick by the addition of an acid. On the whole, since the differences between fluid oils, concrete oils, wax, and resins, consist, in a great measure, in the varieties of consistence; and since the most concrete oils may be attenuated in an almost unlimited manner, by repeated distillations, we may expect that future experiments will shew that these substances, seemingly so various, are much more similar than has been imagined.

The animal oil obtained from jelly gives no indication of the presence of an acid, instead of which volatile alkali enters into its combination. Spirit of wine, digested with strong and dephlegmated alkalis, is converted into an oily or saponaceous substance, without passing through an intermediate ethereal state, as is the case when it is treated with acids.

Essential oils, and their concretions, as balsams and resins, are soluble in spirit of wine,
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but fat oils and bitumens are not. These, and the other properties of spirit of wine, as a solvent, render it exceedingly useful in the hands of chemists, for making the analysis of compound bodies by the moist way.

We have already taken notice of the formation of sulphur in the chapter on acids; and shall only observe in this place, that it is soluble in all oils. For this purpose, an heat sufficient to melt the sulphur must be used. More sulphur is held in solution by oil when hot than when cold, and consequently a part is separated from the oil as it cools: this part takes a regular arrangement, if the cooling be gradual. Oils impregnated with sulphur are called balsams of sulphur.

When compound substances, into the composition of which earth and phlogiston enter, are exposed to heat in close vessels, as in distillation, the volatile parts are all detached and raised, and the earth remains combined with the phlogiston. This combination is called coal, and affords some reason to suspect that the affinity of phlogiston to earth is greater than to any more volatile substance, pure air and nitrous acid only excepted.

Charcoal,

Charcoal, for example, is phlogiston, combined with the earth of wood; for it burns in the air without smoke or moisture, and leaves an earth: and charcoal cannot be decomposed unless pure air, nitre, or some dephlogisticated earth be presented to it in a very heated state. And this being the case, is an additional reason why we cannot expect to obtain phlogiston in an uncombined state.

C H A P. VIII.

Of Metals. Gold. Silver. Platina.

IF a philosophical enquirer were to undertake to search into the component parts of natural bodies, it is probable that his attention would be fixed very early upon those hard substances which contain the metals. Their specific gravity is so great, that the most ignorant person cannot take an ore into his hand without being actuated by a wish to know what it is which occasions its great weight. But the arts originated in times when necessity was the immediate inducement to almost every action. Leisure, and a certain independance of manual labour, have given opportunities to men of genius to systematize and speculate on discoveries which accident had produced long before; and metallurgy, which has been practised from immemorial time, is now become a rational science.

If the word ore be used in its most extensive sense, there are few sands, clays or mud, which do not contain a small portion of metal ; but ores, properly so called, are those substances which contain such a quantity of metal as to give them a remarkable appearance, and to make them worth the miners attention. They are not in general found in any considerable quantity on the surface of the earth, but are obtained by digging. The cavity thus formed in the earth, on this occasion, is called a mine.

Metals are very seldom found pure. They are either mixed or combined with other substances. The state of combination is called mineralization. Gold is never mineralized in its ore, but only mixed and dispersed though the mass. The other metals are almost always in a mineral state, and therefore can seldom be extracted from the ore by pounding, washing, or solution, as gold may. Solid ores are most commonly covered with a kind of encrustation, which mineralogists consider as their matrix. This encrustation consists for the most part of a great number of regularly formed hexagonal crystals, sufficiently
hard

hard to strike fire with steel. Their size, color, and transparency, is various in various ores. They are called quartz. Ores are likewise often accompanied with a less hard stone, called spar, of a rhomboidal quadrangular figure, and of the nature of gypsum. An attention to these and other matrices might perhaps indicate some interesting particulars relative to the earth of metals.

Metals are more frequently mineralized by sulphur or arsenic than by any other substance. The art of refining consists in separating these substances from the metal, taking care at the same time that the metal shall not be deprived of the phlogiston, or reduced to a calx; for in this last state, being much less fusible than otherwise, it would remain mixed with the earthy matters of the ore, instead of melting into a mass at the bottom.

Metallic substances are distinguished from all other bodies by their great weight. They are, gold, silver, platina; copper, iron, tin, lead; mercury: regulus of antimony, bismuth, zinc, regulus of cobalt, regulus of arsenic, and nickel. The eight first are called metals, of which gold, silver, and platina, are

called perfect; copper, iron, tin, and lead, are called imperfect metals; and mercury, on account of its great fusibility, volatility, purity, and other properties, cannot, with propriety, enter into any class. The six last bodies are called semi-metals, because they possess the metallic properties in a less degree than even those metals which are stiled imperfect.

The metallic properties are great specific gravity, fixity, and malleability. Those bodies, which possess all these properties, are called metals. The perfect metals are so termed, because they cannot be deprived of them by mere heat, without addition. The imperfect metals may be very much altered by calcination. And the semi-metals have little or no malleability; besides which, some of them are very volatile, and even combustible, so as to produce an actual strong flame.

Gold is found in a great variety of forms. It is frequently imbedded in quartz, and is found intermixed in larger or less particles among the sands of rivers. These are collected by the natives on the Gold Coast of Guinea, and in Potosi, in South America, and are separated by washing with water, which

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carries off the lighter earth and impurities. The remaining matter is dried, and ground or kneaded with quicksilver, which dissolves the gold, and by shaking in a bag, or otherwise, is collected into a mass, from which the gold may be obtained, by straining through leather, or by fire. The cupel is also used in the purification of gold. It is a shallow dish, or crucible, in which the matter containing gold is exposed, together with lead, to the reverberated flames of a furnace. The lead is converted into glass, and vitrifies every impure metal, or other substance, which either soaks through the cupel, or is blown aside by large bellows, and leaves the gold in a refined state.

But this process is insufficient for the separation of the perfect metals from each other. Silver is separated from gold by parting. The operation of parting consists in exposing the mass to the action of the nitrous acid, which dissolves the silver, but has no affinity with gold, in its aggregate state: the parted gold is consequently left in a porous form, which may be easily broken.

Platina cannot be separated from gold by parting, on account of the similarity of its

properties to those of gold : but if a mixture of gold and platina be dissolved in aqua regia, the platina may be precipitated alone in the form of a yellow powder, by the addition of sal ammoniac ; and, on the other hand, if martial vitriol be added instead of sal ammoniac, the gold will be precipitated singly. In the refining of this, as well as all the other metals, peculiar contrivances are made use of, which are adapted to the state of the ore and the nature of the metal. The detail of these circumstances, though of great importance in practical metallurgy, would be too long for the limits we have prescribed to this work.

Pure gold possesses the metallic properties, without the possibility of their being destroyed by any continuance of heat, human industry has yet devised. It likewise possesses them in the most eminent degree. Gold is thought to be the heaviest, the most unalterably fixed, and the most ductile and tenacious body in nature. Its ductility appears by the instances alledged concerning gold leaf, at the beginning of this treatise. To add to the surprise which such a subtilty or minuteness of particles must

must occasion, we will again take notice of the gilding silver wire to make lace. For this purpose it is usual to gild a cylindrical bar of silver strongly, and afterwards draw it into wire, by passing it successively through holes of different magnitude in plates of iron. By this means the surface is prodigiously augmented; notwithstanding which, it still remains gilt, so as to preserve an uniform appearance even when examined by the microscope. The quantities of gold and silver employed, and the dimensions of the wire are known. With these data, it is easy to calculate, and from calculation it is proved, that sixteen ounces of gold, which, if in the form of a cube, would not measure one inch and a quarter in its side, will completely gild a quantity of silver wire, sufficient to circumscribe the whole globe of the earth.

The great tenacity of gold is proved by suspending a weight at the end of a wire of a determinate thickness, in which situation a greater weight is supported than any other metal of the same thickness would sustain. Gold is not hard, is of a bright

yellow colour, and contracts no rust by exposure to air and water. The colour of different specimens of pure gold is not exactly the same.

When gold is exposed to the fire, it soon becomes red hot. It is not easily melted; but just before the fusion it assumes a lively green colour, which continues during the time it remains fluid. Yet it suffers no alteration by this means. Several philosophers have exposed gold to the utmost violence of fire for more than a month, without finding it sustained any loss or change. However, gold is said to have been vitrified by means of a very large burning lens; but it does not appear that this experiment has ever been made with that caution and accuracy which are necessary to put the matter out of doubt.

Gold, while its aggregation is entire, resists the action of the strongest chemical menstruums, either in the dry or the humid way. It is not soluble, either by the strongest mineral acids, when they are pure, nor by sulphur, nor by alkalis. Two compound bodies nevertheless are powerful solvents of gold.

gold. The first is a mixture of the nitrous and marine acids, called by chemists *aqua regia*, because it dissolves gold, the king of metals; and the second solvent of gold is liver of sulphur.

The solution of gold in *aqua regia* is very easy. A very small quantity of nitrous acid, or even of inflammable matter, added to the marine acid, gives the latter the power of dissolving gold. Also a very small quantity of marine acid, or of any of the salts containing it, added to nitrous acid, renders the nitrous acid capable of dissolving a certain quantity of gold. But experience has shewn, that an *aqua regia* composed of four parts of nitrous acid, and one of sal ammoniac, dissolves perfectly well a fourth, or even a third part of its weight of gold, according to the strength of the acid. Heat is necessary to complete this solution, which is of a fine transparent yellow.

The power which the nitrous and marine acids acquire by their union, of dissolving gold, which neither of them have separately, is one of the most remarkable facts in chemistry.

mistry. If we may judge of the perfect metals from the phenomena which the imperfect afford, all metals are composed of phlogiston united with certain earths. In speaking of the nitrous and marine acids, we observed that the affinity of the nitrous acid to phlogiston is such, that it appears to hold bodies in solution merely by that medium: and it was likewise noticed, that the marine acid, though possessed of very little affinity to phlogiston, was more capable of dissolving metallic calces or earths than other acids were. This being the case, a probable theory may be given of the appearance before us. The earth of gold and its phlogiston adhere together with a prodigious force, as is evident from its property of resisting calcination. The affinity of nitrous acid to the phlogiston is likewise exceedingly great; but not sufficiently so to break and destroy the aggregation of the gold, or, in other words, to dissolve it. Its action, therefore, only diminishes the force by which that aggregation is preserved. The same argument may be urged respecting the affinity between the marine acid and the earth

earth of gold. Now, though the single action of the nitrous acid may be insufficient to detach the phlogiston from the earth, and the single action of the marine acid may be insufficient to detach the earth from the phlogiston; yet it is very probable, that their united efforts may be capable of producing that division, or partial decomposition, in which solution consists.

Liver of sulphur seems to act upon gold nearly on a similar principle. If gold leaf be mixed with melted liver of sulphur, it becomes entirely dissolved, and if the liver of sulphur be then dissolved in water, the gold will pass with the solution through a filter. In this instance the vitriolic acid of the sulphur seems to attack the phlogiston of the gold, while the alkali combines with its earth. And thus a solution is made, which could not have been singly effected either by the sulphur or the alkali.

Solution considered simply, is an union of the integrant parts of one body with the integrant parts of another. It is a combination which seems to take place by the mechanical division, without any real decomposition

composition of the bodies : and therefore, nothing more is necessary for it to take place, than that the mutual affinity of the bodies be sufficiently strong to overcome the attraction by which the integrant parts are united, and form an aggregate. For instance, the nitrous acid attracts the phlogiston of iron sufficiently to destroy the aggregation of the metal, and to reduce it into parts, so fine, that they intermix without destroying the fluidity of the acid ; but its affinity is not so strong as to destroy the attraction between the earth of iron and its phlogiston : and therefore the earth remains suspended by the medium of the phlogiston. This is solution ; and in this no real decomposition takes place. But with tin it is otherwise. The nitrous acid unites with the phlogiston of this metal so strongly, as not only to destroy the aggregation of its parts, but likewise to detach it almost entirely from the earth. Consequently this last is for the greatest part precipitated in the form of a very fixed calx. This is not solution, but decomposition.

By a proper consideration of this, it may easily be understood, that there may be many
menstruums

menstruums which possess a sufficient affinity with a given body, or some of its principles, to hold it in solution, if presented in a state of extreme division, though they may be incapable of acting upon it in an aggregate form. For it is the force of aggregation which is the antagonist to the dissolving power of a menstruum. Many affinities have been discovered, by presenting bodies to each other in the form of very subtile powder, or of steam, which could not have been manifested any other way; and there is reason to imagine, that there are no two bodies but whose particles, if sufficiently detached, would exhibit a mutual affinity. Thus, gold, when precipitated from aqua regia, by means of an alkali, or any other substance which has a stronger affinity to the acid, is in a state of extreme division, and may then be dissolved in any acid, and even by alkalis, with proper management.

Chemical phenomena are very frequently fallacious; and it requires much care and unprejudiced attention to reason properly concerning them. Precipitations, for example,

are usually made by the addition of some substance which engages the menstruum with a greater affinity than the matter already dissolved. But this is not always the case. The calces of metals are precipitated from the nitrous acid by the affusion of the marine acid, not because this latter acid unites with the former, but because it combines with the calces, to which it has a greater affinity than the nitrous acid. This combination, therefore, falls to the bottom neither in the form of a calx, nor a metal, but of a salt. And in like manner, gold may be precipitated from aqua regia, much more readily by the volatile than by the fixed alkali; notwithstanding the affinity of the latter to the acid is much greater than the former. But both the causes of precipitation are united in the use of the volatile alkali. The volatile alkali not only tends to precipitate the gold, by saturating the acid, but likewise by combining the metal, and forming a saline matter, which is considerably heavier than the original quantity of gold. This precipitate is yellow, and is named *aurum fulminans*, from its singular property of exploding with great violence
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and noise, if exposed to a very moderate degree of heat.

The uses of gold, and the ideal value which the consent of mankind has stamped upon it, are too well known to need any enumeration. It is commonly mixed and alloyed with copper, for the purpose of giving it a sufficient degree of hardness; and in this state the proportion of pure gold, or the fineness of any mass is expressed by imagining the mass to be divided into twenty-four equal parts, which are called carrats, and mentioning the proportional quantity of pure gold. Thus a mass containing twenty-two parts of gold, and the rest copper, is called gold of twenty-two carrats fine, and the like is said of other proportions. This proportion, namely, of twenty-two carrats, is likewise called standard gold, because it is the standard of the fineness of the English gold coin.

In fixity and ductility, silver takes the next place to gold. It is mineralized by arsenic and sulphur, and assumes various appearances, according to the manner and proportion of the combination. The methods of refining

it are chiefly founded on its indestructibility by fire. It is sometimes found in a pure or virgin state.

Pure silver is of a shining white colour, and somewhat harder than gold. It appears to be as fixed and indestructible as gold, but its specific gravity and ductility are much less, as is likewise its tenacity. It is not liable to rust, but is very apt to assume a black colour or tarnish, from phlogistic vapours. This property of attaching to itself a greater proportion of phlogiston than is necessary to its metallic state, is not peculiar to silver, but is possessed by it in a greater degree than by any other metal.

Silver is not easily dissolved in its aggregate form by any acid but the nitrous; though with proper management it may be made to unite directly with the vitriolic or marine acids. But the readiest method of forming saline combinations of silver with acids, is to precipitate it from the nitrous acid, by the affusion of the acid with which it is intended to be combined.

Platina is a metal, which has not been attended to till about the middle of the present

cent century. It is found in angular grains in Spanish South America, and is very scarce in Europe. The colour of the grains is metallic, white, lucid, not very brilliant, but intermediate between the white of silver and the grey of iron. They are smooth, and are nearly as hard as iron; but they have scarcely any ductility. Some of them may be flattened on an anvil, while others are broken into small pieces. The specific gravity of platina, in its crude state, is nearly equal to that of gold.

Platina, like pure gold and silver, is free from all smell or taste. It is not susceptible of rust, and is indestructible by the most violent and long continued heat. But the most peculiar and distinguishing property of this metal is its infusibility by the most intense heat of ordinary fires. Yet a small quantity has been fused, and rendered more malleable, by exposing it to the focus of a large burning-glass.

Neither sulphur, nor the pure acids have any action on platina; but it may be dissolved in aqua regia, and also by liver of sulphur.

The action of these matters on platina is however less than on gold. The solution in aqua regia is of a much more deep and intense yellow than that of gold, and it may be precipitated, either by the volatile or fixed vegetable alkalis. But it is remarkable, that the mineral alkali does not produce the least precipitation, nor so much as render the liquor turbid, even though it be added in sufficient quantity to saturate the acid. None of the precipitates of platina have the property of fulminating.

Notwithstanding the extreme difficulty of fusing platina in its natural form, the precipitate obtained by adding sal ammoniac to the solution in aqua regia may be fused without addition, by the intense heat of a forge-furnace, urged by double bellows. The fusion in this case is very imperfect, but the metal is rendered nearly as malleable as silver, and when well hammered, is the heaviest body in nature, being specifically to water, as 20170 to 1000; which is more than one fiftieth part heavier than gold.

All the other metals may be united with platina, and by that union acquire several valuable properties: but the prohibition of the Spanish ministry against exporting this metal from America, prevents its being applied to any use.

C H A P. IX.

*Of the imperfect Metals. Copper. Iron.
Tin. Lead.*

NEXT to the perfect metals, the most fixed and most malleable is copper. It is almost always met with in a mineralized state, and its ores may in general be known by spots of verdigrise interspersed on their surface. Some copper ores are rich in silver.

Pure copper is of a red shining colour. It is very hard, elastic and sonorous, and is affected by the combined actions of air and water, from whence it is much disposed to rust: it emits a very peculiar and disagreeable smell when rubbed, and its taste is equally unpleasant. Every menstruum can corrode and dissolve this metal.

Copper is easily calcined or deprived of its phlogiston, if ignited or melted with access of air. If one end of a polished piece of copper be heated, several successive arrangements

rangements of colours will be produced on its surface, similar to those of the thin plates mentioned in the optical part of this work. This phenomenon is common to all the imperfect metals, and seems to arise from the progressive calcination of the parts of the surface. For a certain part of the surface is calcined in a given time, and the thickness of that part is determined by the degree of heat : and since the degree of heat diminishes as the distance from the heated end increases, so also must the layer of calcined matter diminish in thickness. The series of colours must therefore be exhibited by reflection, according to the several thicknesses *.

By a sufficient degree of heat, the calces of copper may be converted into glass of a reddish brown colour. The calces of this, and indeed of all the imperfect metals, may be reduced to their metallic form, by being heated with phlogistic matters ; but the reduction is the more difficult in proportion as the calces are more completely dephlogisticated.

* Book II. Section I, Chap. VIII.

The salts and precipitates formed by the solution of copper, are of great use in the arts. Such are blue vitriol and verdigrise and the precipitates which are obtained by adding calcareous earth, or alkalis, to a solution of copper in the nitrous acid.

It is a general effect with solutions of the imperfect metals in acids, that if a precipitate be obtained by the addition of an alkali or an earth, that precipitate is a calx of the metal previously dissolved. But if another metal, whose affinity with the menstruum is greater than that of the metal previously dissolved, be added instead of the alkali, this last will be precipitated in its metallic form. Or, lastly, if the metal be precipitated by the affusion of another acid, whose affinity to the metal, or its earthy principle, be greater than that of the menstruum in which the solution was made, the precipitate will be a salt. The natural inference from this is, that metals are most commonly held in solution by the medium of their phlogiston, and cannot be precipitated in their metallic state, except by the addition of another body, which is capable
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of supplying the precipitating calces with phlogiston. Such bodies are metals.

Iron is the next metal in fixity to copper. Most of the minerals called iron ores, have an earthy, rusty, yellowish, or brownish appearance. This metal is by far the most abundant of any. There is scarcely an earth, a sand, a chalk, a clay, a vitrifiable, or calcinable stone, or even the ashes of any substance, which does not contain an earth convertible into iron. The loadstone is an ore of iron.

Iron is a metal of a white lucid greyish colour. It is the hardest and most elastic of all metals, and, except platina, the most difficult to be fused. Its tenacity is likewise greater than that of any other metal except gold.

That which is generally called iron is not sufficiently metallized, on account of the difficulty of bringing a large mass into a good fusion. In the forges or iron-works, the hammer is in some measure made to supply this defect. For by repeated ignition and hammering, the iron is, as it were, kneaded, and the earthy parts worked out to its surface,

while the metallic parts are welded or united together. But the purest iron is that which is known by the name of steel. In this all the properties of iron are found in the most eminent degree. It is obtained by supplying the best common iron with that phlogiston, which is wanting to completely metallize its earthy part. Steel is made by fusing a quantity of iron in contact with charcoal, or even without fusion, by a process called cementation. The cement is formed of two parts of charcoal, and one of wood-ashes, well powdered and mixed together. The bars of iron are placed vertically in a cylindrical crucible, and are surrounded with the cement, so that they may be an inch distant from each other, and from the sides and ends of the crucible. In this situation the cover of the crucible is carefully luted on, and the whole exposed to an equal red heat for about eight or ten hours; at the end of which time, the iron is found to be converted into steel. Yet as there may be impurities in the bars of some other kind than the unmetallized earth, this steel will be rendered purer, and of a more even texture, if it be afterwards fused.

This remarkable property, of becoming metallized without fusion, is peculiar to the earth of iron.

Iron is the only metal that is hard enough to strike fire with vitrifiable stones, or with itself. It is a combustible substance, and when exceedingly heated, burns in a sensible manner. A number of vivid and shining sparks shoot out from it, which burn with a kind of decrepitation, and at length it is converted into a calx. But though iron may be easily calcined, it is very difficult to deprive the calx of the last portions of phlogiston.

A very remarkable phenomenon appears in the precipitation of iron from its solvent, by the addition of an alkali which has been previously calcined with bullocks blood, or some other phlogistic matter. The precipitate is of a fine blue, is insoluble in acids, and is known by the name of Prussian blue.

The theory of prussian blue is embarrassed with many difficulties. There can be little doubt but that the alkali obtains or becomes combined

combined with phlogiston, by calcination with inflammable substances. In proportion as this phlogistication is more perfect, so much the more does the alkali appear to be deprived of its peculiar properties; and if saturated with phlogiston, it loses its power of combining with, and neutralizing, acids. But if the phlogisticated alkali be added to an acid already combined with iron, the united attractions of the acid to the alkali, and of the iron to the phlogiston, occasion a decomposition, which neither could singly have effected. The acid unites with the alkali, and forms a salt in solution of exactly the same nature as would have been produced by the addition of a pure alkali, while the phlogiston of the alkali unites with the iron, and forms the blue precipitate. If the alkali used for this purpose be not well phlogisticated, as is seldom the case, the precipitate is impure, and green, consisting partly of prussian blue, and partly of an ochreous calx: this last may be dissolved by the affusion of marine acid on the precipitate, after previously separating it from the menstruum by filtration.

Prussian blue then is iron, superabundantly phlogisticated. A slight calcination expels the excess of phlogiston, and restores it to the state of iron : likewise a solution of very pure alkali being poured on prussian blue, deprives it of its color, and reduces it to an ochre ; the alkali at the same time becoming completely phlogisticated, if the quantity of prussian blue be sufficient. Here it is observable, that the affinity of the alkali is greater than that of the iron to the coloring matter of the prussian blue, since it attracts it from the latter ; and that iron can only become prussian blue when there is an acid present, which, by attaching itself to the alkali, weakens its attraction to the phlogiston.

But the great difficulty of this apparently consistent and obvious theory is, that if phlogiston be the medium of affinity between acids and metals, and even alkalis, as there is great reason to imagine, it is strange that an excess of phlogiston should destroy that affinity. If this be true, there must be a certain maximum of affinity between acids and metals, for example, iron, which will depend on a precise proportion of phlogiston in the latter,
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and will be diminished either by adding to, or subtracting from that proportion. Prussian blue, for instance, is insoluble in acids: a slight calcination renders it soluble; a greater calcination renders it less soluble. The metallic state then is a kind of medium between a calx and a superphlogisticated combination: from which it seems to follow, that an alkali, phlogisticated to a certain degree, ought to precipitate iron in its metallic state; which, nevertheless, does not happen. Notwithstanding these objections, it is probable that the theory is true, and, if well understood, would perhaps lead to discoveries of importance: but in order to promote that caution, which cannot be too much inculcated in philosophical matters, we have chosen to speak in an indeterminate manner.

All vegetable astringent substances, as galls, pomegranate rind, &c. precipitate iron from its solvents in a black powder, or mud. This black powder seems to be formed by a process something analogous to that which obtains in making prussian blue; but it differs from this last substance in several respects, particularly in that of being soluble in acids. If gum be
added,

added, together with galls, to the solution of iron, the precipitate is formed, but is kept suspended in the liquid by the mucilaginous quality of the gum; constituting that black fluid, which is known by the name of ink.

The affinity of iron to sulphur is very great, and exceeds that of any other metal to that substance. It is therefore successfully employed as a medium in the depuration of several sulphureous ores. Iron is considerably more fusible when combined with sulphur than when alone. If a bar of iron, heated to a white heat, be applied to a roll of sulphur, a combination takes place; and the melted matter, which falls, is a kind of pyrites, formed of both substances. This experiment ought to be performed over a pail of water, that the melted matter being immediately extinguished, may not incommode the operator with its fumes.

The decomposition and spontaneous accension of ferruginous pyrites have already been mentioned. These effects are produced but slowly, on account of the small proportion of iron, and a quantity of earth, which enters
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into the composition of these natural bodies. But if equal weights of iron-filings, and powdered sulphur, to the quantity of twelve pounds or more, be kneaded together into a paste with water, the mixture, in a few hours, will swell, become hot, melt, emit vapors, and take fire. The rationale of this has been sufficiently explained in speaking of the vitriolic acid.

Iron is a very destructible metal. It is strongly acted upon by most menstrooms, and in some degree by all: whence it is very subject to rust.

But the most uncommon and peculiar property, which distinguishes this useful metal from every other substance on earth, is the attractive or repulsive force which one piece of iron exerts on another at a very sensible distance. Several of the ores of iron possess this property, and are called loadstones, or magnets, and the property is called magnetism. Iron which has been extracted from the ore by art is not sensibly magnetical, but may be rendered so by rubbing, filing, electrifying, contact with a magnetical substance, or by long remaining in one position. This
attraction

attraction and repulsion being the only permanent power of the kind which comes under the immediate cognizance of the senses, may, perhaps, in some future time, serve as a clue to direct the pursuit and discovery of the causes of the attractions of gravity, the attractions and repulsions of cohesion, electricity, &c. and is of such importance both to philosophy and the practical sciences of navigation and geography, in their most extensive sense, that it will be proper to treat of it in a separate chapter.

The great hardness of iron renders it extremely useful for the construction of all cutting tools. If heated, and plunged suddenly in water, it becomes very hard and brittle. This operation is called tempering, and is such, that steel is often made sufficiently hard to cut glass.

Tin is seldom found in a virgin or pure state. Its ores are various; but the richest is a stone of a blackish brown color, and is much heavier than ores in general are. The cause of this is, that arsenic is the substance with which tin is combined in its mineral state; whereas other metals are usually mineralized

ralized by sulphur, which is a much lighter body than arsenic.

Tin is of a white color, resembling silver, though less beautiful. It is the lightest of all metals, and, except lead, the softest and least elastic. Less heat is required to melt tin than any other metal, and it may be easily reduced to a calx, which is very refractory, but may, however, be vitrified by a violent heat in particular circumstances. This metal may be attacked and dissolved by all the acids; and the phenomena it affords are various and interesting. Nitrous acid attacks tin with great violence, but seems to unite very little, if at all, to its earthy part; this latter, therefore, is continually precipitated in the form of a white calx, which is very difficult of reduction. When tin is dissolved in the vitriolic acid, sulphureous vapors are emitted, and small particles of black inflammable sulphur are observed swimming in the menstruum. These circumstances, added to the readiness with which tin may be calcined by fire, seem to indicate that the adhesion between its phlogiston and earth is very weak.

Tin is not much subject to rust, but contracts a superficial tarnish, from the action of the atmosphere, which does not enter deeply into its substance. It is therefore advantageously used in tinning copper utensils, and covering the surfaces of those thin plates of iron which are commonly called tin. The composition called pewter consists of tin, alloyed with a small proportion of copper, bismuth, lead, and zinc.

All metals may, by fusion, be combined with tin, and in all proportions. It renders them much more brittle and sonorous. The speculums of reflecting telescopes are made of a mixture of tin and copper. If tin be added to mercury, a solution, or perhaps mixture, takes place, and the mercury becomes less fluid in proportion as the quantity of tin is greater. If the proportion of tin be very great, a kind of paste is formed, called amalgama. The greater part of the mercury, which is thus united with tin, may be separated by straining through a piece of leather; which seems to indicate, that no real solution takes place. From the specific gravity of the amalgama, there is reason to conclude,

that the integrant parts of tin are at least of as great specific gravity as those of mercury.

The silvering of looking-glasses is an amalgama of this kind. For, quicksilver being diffused on a leaf of tin-foil, the glass is slipped upon the surface, and, by means of weights, is pressed down so as to exclude the superfluous quicksilver. The amalgama adheres to the glass, and in a short time is sufficiently hard to be handled and applied to use.

Lead is almost always found in a mineralized state. In general it is mineralized by sulphur, and appears of a dark white metallic color, internally composed of cubes of different sizes applied to each other, but not adherent. The ores of lead almost always contain silver.

Lead is of a blueish white, and has less hardness, ductility, tenacity, or elasticity, than any other metal. Its weight is considerable, being the heaviest body in nature, except gold, platina, and mercury. It is nearly as fusible and calcinable as tin, but its calces are not so refractory. For they cannot be made to part with the last portions of phlogiston, and are very easily revived and converted again into lead. In the calcination of lead by a moderate

moderate fire, the calx is first grey; then yellow, called mafficot; then red, called minium, or red-lead: if the fire be increased, the red-lead is converted into a pale red or yellow vitrified substance, called litharge; and if it be still more urged, a true vitrification takes place, and the litharge becomes glass of lead. Glass of lead is so fluid and active, that it passes thro' the most compact crucibles. These substances are all of great use in the arts.

Lead is soluble by all acids, and presents nearly the same phenomena as silver. It is subject to rust by exposure to the air, but much less so than either iron or copper. Sheet-lead, exposed to the vapors of vinegar, becomes covered with a rust of a beautiful white color, called ceruse, or white-lead.

The purposes to which lead is applied are very numerous. Its application to the purifying the perfect metals by the cupel has already been explained. The ease with which its calx may be fused renders it very advantageous as a flux in the preparation of enamels. It enters into the composition of most fine glass, and is the basis of the glazing of all the better kinds of pottery.

C H A P. X.

Of Mercury, or Quicksilver.

MERCURY is frequently found pure, but much oftener combined with sulphur, in the form of red masses, composed of needle-like parallel striæ. This mass is called native cinnabar. There is another ore of mercury, of a blackish grey color, of a glassy texture, and brittle, which contains a small proportion of copper. But this ore is seldom met with.

Mercury, which is also called quicksilver, cannot easily be extracted from cinnabar by mere heat; for the mercury and the sulphur being both volatile, are sublimed together, without alteration, in close vessels. An intermediate fixed substance must therefore be used, whose affinity with the sulphur is greater than that of the mercury. There are many such, but iron is most frequently made use of. If iron-filings and pounded cinnabar be mixed,
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and submitted to distillation in a retort, the iron combines with the sulphur, forming a pyritous compound, and the mercury passes over in fumes, which are condensed by water previously put into the receiver for that purpose.

This metallic substance is singular in possessing a very great degree of fusibility and volatility. Its color is of a shining white, and it does not appear to be susceptible of rust from exposure to the air. Gold and platina excepted, it is the heaviest body known. In our climate it is always melted or fluid; but in December, 1763, the cold in *Siberia* was so intense, that quicksilver was condensed into a soft substance like pewter. In this state it was malleable, and its flexibility seemed to be intermediate between those of lead and tin. The beginning congelation of mercury is at seventy-eight degrees of *Fahrenheit's* thermometer, below the freezing point of water. But the actual consolidation of mercury was before ascertained in December, 1759, by the academicians at *Petersburgh*, who availed themselves, during a very severe season, of the

extreme cold which is produced by the affusion of strong spirit of nitre upon snow. This last experiment has been repeated at Hudson's Bay in 1775 *.

Repeated distillations of pure mercury produce no change; but if mercury be exposed in a large flat-bottomed matrafs, with a long neck, open at top, to the greatest heat it will bear, without volatilizing, its surface gradually, in the course of two or three months, becomes covered with a red powder, which floats on the fluid mercury without mixing with it. This powder is called precipitate of mercury without addition. It is supposed to be a calx of mercury, but may be revived merely by increasing the heat. It is therefore more probably mercury, combined with air in such a manner as to approach to a saline state.

Several chemists have taken occasion to object against the doctrine of phlogiston, from observing the revival of metallic calces without addition. It is an indubitable fact, that the calces of metals, whether obtained by fire

* See the Philosophical Transactions for 1760 and 1775.

or precipitation, are more heavy absolutely than the metals from which they were produced; and it is as certain, that they produce or give out air when they are restored to their metallic state. Why, then, say the objectors, should we not attribute the calcination of metals to the addition of the principle air rather than to the subtraction of the principle phlogiston? — Tho' this objection is strong, yet, for want of experiments, it is not sufficiently decisive to induce us to give up the very probable and consistent theory of phlogiston, which seems to be supported by many other, and independant proofs.

The nitrous acid readily dissolves mercury, and forms a crystallizable salt. If this salt be submitted to heat, a great part of the acid may be driven off, and a red matter is left, called red precipitate, which has a considerable analogy with the precipitate per se, or without addition. In fact, all metallic salts may be thus decomposed, and deprived of most of their acid by mere heat. Their remaining fixed part seems to indicate the nature of metallic calces. Thus, the rust of iron, verdigrise or the rust of copper, ceruse

or the rust of lead, and other similar substances, which are usually termed calces, approach to the nature of salt in proportion as they depart from that of metal. An addition of acid brings them into a saline state, and perhaps a subtraction of the acid they are known to possess, might reduce them to the state of metal. If this supposition were confirmed by experiment, as in some instances it is, it would establish the doctrine of those who deny that the phlogiston is concerned in the calcination of metals. We should then say, that the calcination of metals is produced by exposing them in a very heated state to air, which, by combining in part with the metal, becomes itself diminished, and reduces the metal to a semi-saline substance, called a calx. The diminution of the air produces an increase of weight in the calx into the combination of which it enters; and the reduction cannot in general be produced by mere heat, but requires the apposition of another body, which, when heated, can absorb the air. This property is possessed in a surprising degree by charcoal, which, on that account, is very useful in reducing calces to a metallic state. The great impor-

tance of these considerations render them deserving of the utmost attention of the experimental enquirer; and their elucidation would probably remove many difficulties relating to precipitates; as prussian blue, and the like.

The vitriolic acid, well concentrated, and hot, dissolves mercury, and forms a combination called turbith mineral, or yellow precipitate, which is insoluble in water. The marine acid does not attack mercury in its crude state, but with proper management they may be combined in the form of vapor, which adheres to the sides of the subliming vessel. This salt is called corrosive sublimate. All the other acids may be combined with mercury, by previously dissolving it in the nitrous acid, and afterwards pouring in the acid in question, which seizes the mercury, and falls with it to the bottom, in the form of a saline precipitate.

We have seen, that mercury may be combined with sulphur in native cinnabar. If mercury be triturated in a glass mortar with sulphur, it combines with it, forming a black powder, called ethiops mineral. This combination becomes more intimate, by exposing
the

the ethiops to heat in a matrafs, by which it is fublimed, and converted into cinnabar. Repeated fublimations, and a fkilful management of the fire, are neceffary to produce that beautiful factitious cinnabar, which is known in the fhop by the name of vermilion.

Mercury unites alfo with oils and mucilages by trituration, and by that means is made to enter into the compofition of many very ufeful medicines.

All the metals and femi-metals may be amalgamatized with mercury. This union is difficultly made with copper, more fo with regulus of antimony, and moft difficultly of all with iron; infomuch, that many philofophers have concluded this laft combination to be impoffible.

C H A P. XI.

*Of the Semi-metals. Regulus of Antimony.
Bismuth. Zinc. Regulus of Cobalt. Regu-
lus of Arsenic. Nickel.*

SEMI-METALS are substances which possess all the metallic properties, except malleability and fixity. They are incapable of any considerable extension under the hammer, and are so volatile, that they may be totally sublimed by fire. These, as we have already enumerated them, are, regulus of antimony, bismuth, zinc, regulus of cobalt, regulus of arsenic, and nickel.

Antimony is an ore or mineral, of a brilliant leaden color, composed of long brittle needles, or parallel striæ. It is composed of nearly equal parts of sulphur, and the semi-metal regulus of antimony. If antimony be submitted to calcination, the sulphur is gradually evaporated, and the regulus, being deprived of part of its phlogiston, takes the form of a grey calx. A more violent heat fuses

fuses this calx, which, according to the management of the fire, coagulates into an opake brown mass, called liver of antimony, or else into a transparent hyacinthine glass, called glass of antimony. But a more perfect calcination renders the residue incapable of either fusion or vitrification. These calces being treated with phlogistic matters in close vessels, are reduced into the semi-metal or regulus.

The regulus of antimony is of a dull white color. It is hard and brittle, and seems composed of shining facets; and its specific gravity, being to that of rain-water as 7500 to 1000, is rather greater than that of tin.

Antimony, being supposed necessary to the great work of transmutation of metals, which was attempted by the alchemists, and which is still pursued by numbers whose knowledge of chemistry is too superficial to permit them to see the great difficulty of their undertaking, has been submitted to a great variety of chemical trials. In consequence of this, our knowledge of antimony is very considerable; and many valuable medicines are obtained from it: but our purpose does not admit of extensive details.

If a mixture of antimony, tartar, and nitre, be thrown by spoonsful at a time into a red hot crucible, the nitre detonates with the phlogiston of the tartar, and the sulphur, which is a part of the antimony. When the whole is put into the crucible, the fire must be raised to melt the matter, which, when cool, may be obtained by breaking the vessel. This matter consists of two distinct substances, which may be easily separated. At the bottom is the regulus of antimony; and the upper part is a scoria, composed of the alkaline parts of the nitre and tartar, combined with a portion of the sulphur, and the regulus of the antimony. It is consequently a liver of sulphur, which holds a part of the regulus in solution.

All the imperfect metals have a greater affinity to sulphur than the regulus of antimony has, and are, for that reason, employed to separate it from the ore. Iron is most commonly used. Crude antimony being melted with bits of iron, by a strong fire suddenly applied, the sulphur unites with the iron, and forms a mass which swims at the top of the vessel, while the regulus occupies the lower part of the crucible. If
the

the iron be greater in quantity than is necessary to saturate the sulphur, the surplus unites with, and vitiates the regulus; it is therefore requisite to attend to this circumstance.

In the calcination of antimony, a part always sublimes in the form of flowers. The whole of this ore may be sublimed by heat in half-closed vessels, and is then called flowers of antimony. The regulus is also capable of sublimation into flowers, which are called silvery flowers, or snow, of regulus of antimony. These last are esteemed to be the calx of the regulus, and are reducible by being treated with phlogistic matters. But this calx is soluble, though difficultly, in boiling water, and therefore seems to confirm, in some degree, the conjectures relating to the saline nature of metallic calces, which were adverted to in the last chapter.

The simple acids cannot be made to combine with the regulus of antimony without particular management. For this purpose the vitriolic acid must be concentrated and hot. The nitrous acid rather corrodes and dephlogisticates than dissolves it. And the marine acid exerts no action upon it unless both be in
the

the state of vapor. If regulus of antimony and corrosive sublimate be submitted to heat in a vessel of a proper form, the marine acid of the corrosive sublimate quits its mercury, and unites with the regulus to which it has a greater affinity: this last combination is sublimed in the form of a very corrosive salt, called butter of antimony. The mercury is left at the bottom of the retort, but may be obtained by increasing the fire. If, instead of the regulus, antimony itself had been used, the last product would have been cinnabar, and not mercury; for the sulphur of the antimony, combining with the mercury, causes it to be sublimed in this last form. Cinnabar obtained by this means is called cinnabar of antimony.

The proper solvent of regulus of antimony is aqua regia, but this must be assisted by heat. If the aqua regia be evaporated, the regulus is left in the form of a white powder, which, when nitrous acid has been twice poured over it, and evaporated by a heat sufficient to calcine the residue, is called bezoar mineral. But in making bezoar mineral, it is better, and more usual, to dissolve butter

of

of antimony in the nitrous acid; in which case the regulus, after the commotion of the liquor has subsided, is held in solution by an aqua regia, composed of the nitrous acid and the marine acid of the salt. The subsequent affusions of nitrous acid and calcinations are managed as before.

Bismuth is the heaviest of all metallic bodies, except the perfect metals and lead. It is also called tin-glass and marcasite. It appears to be composed of cubes, formed by the application of plates upon each other, and is of nearly the same glittering color as regulus of antimony. Bismuth is generally mineralized by arsenic, and its ore almost always contains cobalt; but it is sometimes found native.

This semi-metal resembles lead in many particulars. It may be vitrified, and converted into a kind of litharge; and is thought to be superior to lead for purifying gold and silver by the process of cupellation. Its fusibility is very great, and it very much increases the fusibility of tin, and other metals. And it is so volatile, that it may be sublimed entire in close vessels, without altering any of its properties.

It is not easy to combine bismuth with either the vitriolic or marine acids, but the nitrous acid dissolves it very well. From this solution, by evaporation and cooling, is procured a shining white salt. But if, instead of evaporating and cooling, water be added to the solution, the nitrous acid unites with the water, and quits the bismuth, which falls to the bottom in the form of a white powder. This powder is called magistery of bismuth, or more commonly spanish white, and when washed and dried is used as a cosmetic or paint, in which, however, it is pernicious.

Zinc is a semi-metal, of a brilliant white. It is ductile in a small degree, and when broken presents a surface, composed of shining facets, which are larger when slowly than when hastily cooled. It is brittle when heated, and is so inflammable that it burns, when exposed to a white heat, with a flame too bright to be viewed without pain. During this inflammation it sublimes in the form of a white smoke, which, becoming condensed, floats in the air like spiders webs, and is called philosophical wool, pompholix, or flowers of zinc. These flowers are very fixed, and of the nature

of calces, notwithstanding their subliming by the violent inflammation.

There are various ores of zinc. *Lapis calaminaris*, or calamine, is the most common. It is a yellowish rusty stone, found in Cornwall, and other parts, and is generally used for making of brass.

The specific gravity of this semi-metal is to that of rain-water as 7215 to 1000. It possesses the property of not uniting with sulphur, and may therefore be purified from the imperfect metals by burning sulphur on its surface when melted, which destroys the latter. Brass, and all the various imitations of gold, called princes-metal, tombac, &c. are allays of copper with zinc.

All the acids are capable of acting upon zinc, and form saline compounds. White vitriol is a combination of the vitriolic acid with this substance.

Cobalt is a term which has been used with some latitude by mineralogists; but is now generally understood to imply that mineral which contains a regulus or semi-metal, whose calx furnishes a blue glass when vitrified. Cobalt is of several kinds, but most commonly

monly of a grey color, with some degree of brilliancy, and its surface, after exposure to the air, is generally covered with an efflorescence or powder. This ore contains much arsenic, which sublimes, and is collected in long crooked chimneys during the torrefaction or roasting, which is necessary for procuring either the calx or regulus. The residue or calx is of a grey or reddish color, and is called zaffre. If zaffre be fused with vitrifiable matters, it affords a beautiful blue enamel, called smalt, or azure, which is of considerable use in the arts. But if, instead of vitrifiable matters, the zaffre be fused with a proper quantity of black flux, which is a phlogistic, or coaly alkaline matter, that remains after the detonation of one part of nitre with two parts of crude tartar, a metallic regulus is obtained at the bottom of the crucible. This regulus on examination is found to consist of two distinct semi-metals, which may be separated at their common horizontal surface by the blow of a hammer. The lower part is the semi-metal bismuth, which is almost always contained in cobalt, and the

upper part is the regulus of cobalt, whose calx possesses the distinguishing property of imparting a blue to glass, which is proof against the utmost violence of heat.

Regulus of cobalt is a hard, brittle, close-grained semi-metal, of a silvery white, very brilliant when newly produced, but subject to tarnish in the air. It ignites long before it fuses, and requires for this last purpose a heat sufficiently great to melt copper. Its fixity is much greater than that of any other semi-metal, but it may be volatilized by an intense heat. A less degree of heat, with access of air, reduces it to a blackish calx, which forms the beautiful blue glass before-mentioned, by fusion with vitriifiable matters.

The regulus of cobalt is not acted upon by either the vitriolic or marine acids, but by means of heat, and a skilful management of circumstances. The nitrous acid attacks it with impetuosity, and forms olive colored crystals of salt, by evaporation, which are very deliquescent. The properties of this semi-metal, are not much known.

Arsenic is a substance, which, as far as it is yet known, cannot with propriety enter into any class of bodies. It consists of the white flowers which are obtained in the torrefaction of several ores, but particularly that from which cobalt is obtained.

Arsenic appears to be a metalline calx; for if it be combined with phlogistic matters, it sublimes in the form of a scaly brilliant substance, which has the metallic opacity, weight, and lustre, and is called regulus of arsenic.

Yet the volatility of arsenic constitutes an essential difference between it and metalline calces: besides which, it easily unites with all metals and semi-metals; a property which no other substance, not, actually in a metallic state, possesses.

But this singular body, notwithstanding the properties we have just enumerated, possesses many of the distinguishing characters of salts. It is soluble in water and in acids, and acts even as a strong acid in the perfect neutralization of alkalis.

Sulphur combines with arsenic, and forms compounds of a yellow or red colour, accord-

ing as the proportion of the latter is greater or less. The yellow is called orpiment, and the red reagal or risgal. These combinations, as also arsenic, and even its regulus, are sometimes found native.

The combinations of arsenic with acids have not been enough examined. Its solution in water yields by evaporation red and irregular crystals. If arsenic be added to nitre, and the mixture submitted to distillation, the arsenic acts as an acid, by combining with the alkaline base of the nitre, and detaching its acid. The nitrous acid therefore passes over into the receiver, together with a small portion of the arsenic, while the bulk of the arsenic remains behind in combination with the alkali, forming a salt. This salt is termed neutral arsenical salt, and, after the usual purification by solution, filtration, and evaporation, may be obtained in beautiful crystals.

Arsenic and its combinations are used by dyers and other artists. It is not applied to any purpose in medicine, being a most violent and corrosive poison. The best antidotes against its effects, when taken, are diluting

or emollient drinks, as mucilages and oils. Soap might perhaps be a ready and advantageous remedy, as the alkali of this substance, by combining with the arsenic, might diminish its violence by neutralizing it.

The last semi-metal is nickel. It is of a white colour inclining to red, and its specific gravity is to that of rain-water, as 8500 to 1000. Its fixity is considerable, and its calx is green. It is soluble in all the acids, though difficultly in the vitriolic; and all these solutions have a deep green colour. The vitriol formed of it is likewise green, and this vitriol, as also the precipitates from the solution, are green when calcined. But no copper can be obtained by reducing the precipitates. Except silver, quicksilver, and zinc, it unites with all metallic substances. It strongly attracts sulphur. A strong fire is necessary to melt it, which does not follow till some time after ignition.

This substance is obtained from a reddish yellow mineral, called kupfer nickel, which contains also iron, regulus of cobalt, arsenic, and sulphur. It has been conjectured that nickel is a kind of regulus of cobalt; but

the present state of our knowledge does not enable us to determine on the matter.

C H A P. XII.

Of Saline Substances.

HA V I N G dispatched the first general class of compound bodies, namely, the inflammable, or such as contain phlogiston, we shall now proceed to treat of the second class, which consists of substances which are either divested of that principle, or else combined with it in such a manner and proportion as to be incombustible. These are pretty accurately denoted by the general term salt.

The general definition of salt is, that it is a substance which is uninflammable, and soluble in water.

This definition comprehends those bodies which are called acids and alkalis, as well as more compounded matters. Acids and alkalis were always termed salts by the old chemists; but many of the moderns have with reason confined the word to denote substances
which

which are evidently compounded. These almost always consist of an acid combined either with an alkali, a metal, or an earth. The substance, which, by uniting with an acid, forms a salt, is called its base.

We have frequently adverted to the great variety which subsists in nature, and have observed the imperfection which must consequently attend all general classification. The conditions of any definition are always found to agree more perfectly with one specimen of the class than another; which evinces, that we are yet far from the knowledge of the first principles of bodies. In the present instance, solubility in water is the criterion by which salts are distinguished from earths: yet, if we attend to the various degrees of solubility, we must see that the limitations of each class approach by a gradation which is imperceptible. Selenites, or the salt which is composed of the vitriolic acid united with calcareous earth, is soluble in very small quantity. Pure calcareous earth is likewise so. The saline combination of an alkali with vitrifiable earth, called liquor of flints, is soluble in water: a similar combination in which the proportion

of alkali is less, becomes glass, and is insoluble, at least to sense and common experiment. In these and many other instances, the difference is not in specie, but in degree only; and therefore, it does not appear inaccurate or improper, to denote all uninflammable combinations by the term salt.

There are also salts of considerable simplicity, which contain phlogiston, and are inflammable. Such are tartar and the volatile alkali, both which are sufficiently phlogisticated to cause a detonation with nitre.

Sapidity or taste is usually reckoned as one of the properties of salts; but this observation does not seem to render the definition more accurate. Sapidity is a degree of causticity, which arises from the whole elective attraction of one or more of the principles of a body, not being saturated, and which can act upon the tongue. Salts are therefore more or less sapid, accordingly as this saturation is less or more perfect. Thus selenites is insipid, common salt is pungent, but lunar nitre is intolerably caustic.

The method of obtaining salts in a state of purity is founded chiefly on their property
of

of combining with water. Thus, * vitriol is obtained, by dissolving the efflorescence of pyrites in water. And as, in general, they are less volatile than water, they may be deprived of it by evaporation. The greater number of salts are soluble only in a certain proportion in water, and form a brine, which, when saturated, will act no more upon the species of salt made use of: but there are others which combine with water in all proportions, and form a magma. If a solution of the former be exposed to heat, the brine becomes more and more concentrated by the evaporation of the water, and part of the salt, being no longer held in solution, becomes solid in the form of crystals, whose figure is different, according to the nature of the salt. This is called crystallization, and the salts are called crystallizable. But a solution of the latter kind of salts only becomes more and more thick by evaporating the water, and at length dry. These salts in general attract the moisture of the air, and become again fluid; whence they are termed deli-

* Page 188.

queſcent. Several cryſtallizable ſalts will deliqueſce, if expoſed to the moiſture of the atmofphere; and others, on the contrary, will dry, and fall into a powder or efflorefcence. A certain proportion of pure water enters into the compoſition of the cryſtals of ſalts, which is called the water of cryſtallization. In many ſalts this water may be driven off by heat, and others may be deprived of it by efflorefcence, without altering their properties.

Heated water, for the moſt part, will hold a greater quantity of a given ſalt in ſolution, than water which is more cold. This varying ſolubility, which depends upon the temperature, is exceedingly different in different ſalts.

In order therefore to procure ſalt in a pure ſtate, the ſubſtance containing the ſalt is mixed with a ſufficient quantity of water, which becomes impregnated with the ſaline matter. The water or brine is then ſeparated from the indiffoluble impurities by filtration or ſtraining, and the ſalt is obtained either in cryſtals or in a maſs, by boiling and evaporating the water.

The

The chief difficulties that attend this process, are, first, that several different kinds of salt may be contained in the same substance, which must consequently all be dissolved together in the water: and secondly, that several saponaceous or mucilaginous matters may be dissolved, which are not only incapable of crystallization themselves, but prevent the crystallization of the salts. The last particular is that which is the most embarrassing; but chemistry affords methods to obviate both.

Since no two salts agree exactly in solubility, they may be separated by means of this difference. Thus, for example; a solution of nitre and common salt being given, it is required to separate them from each other. This is effected by a slow evaporation of the water: for common salt being much less soluble than nitre, begins to crystallize much earlier, and may be taken out with ladles; and the nitre, by cooling, at last crystallizes in a state of considerable purity. This operation must be repeated three times, by adding fresh water, before the nitre is sufficiently pure to make gun-powder.

The

The mucilaginous matter which prevents crystallization, always accompanies the native or combined salts of vegetables. For this reason it is, that the decoctions of vegetables, or their expressed juices, instead of affording the salts, are reduced to the state of an extract by boiling. This difficulty may be avoided, either by treating the vegetable with spirit of wine, which dissolves the salt without affecting the mucilage, or by adding certain matters, as clays, calcareous earths, or alkalis, to the watery decoction or juice, which forward the crystallization, either by combining with the mucilage, or by some other action which has not been sufficiently explained. The first of these methods is never used, on account of the expence; but it is by means of the latter, that tartar is converted into that pure white salt, called cream of tartar; and sugars are refined into sugar-candy or loaf-sugar. Vegetable salts are all very much compounded, and contain phlogiston: and it may be expected, that the laudable industry of the chemists of the present age will discover some method of shortening the tedious and difficult processes by which they are now obtained.

ACIDS.		BASES.				
	combined with	VEGETABLE ALKALI.	MARINE ALKALI.	VOLATILE ALKALI.	CALCAREOUS EARTH.	ARGILLACEOUS EARTH.
VITRIOLIC.		Vitriolated Tartar.	Glauber's Salt.	Vitriolic Ammoniac.	Selenites.	Alum.
NITROUS.		Nitre.	Cubic Nitric.	Nitrous Ammoniac.	Nitrous Selenites.	Little known.
MARINE.		Regenerated Sea Salt.	Sea Salt.	Sal Ammoniac.	Liquid Shcll, or Oil of Limc.	Unknown.
ACETOUS.		Regenerated Tartar.	Sal Diureticus.	Spirit of Minderevus.	Little known.	Unknown.
ACIDS.		BASES.				
	combined with	SILVER.	COPPER.	IRON.	LEAD.	MERCURY.
VITRIOLIC.		Lunar Vitriol.	Blue Vitriol.	Green Vitriol.	Unknown.	Turpeth Mineral.
NITROUS.		Lunar Nitre.	Cupreous Nitre.	Marial Nitre.	Nitre of Lead.	Nitre of Mercury.
MARINE.		Luna Cornea.	Little known.	Little known.	Plumbum Corneum.	White Precipitate. Corrosive Sublimate. Sweet Mercury.
ACETOUS.		Unknown.	Cryffals of Venus, or Distilled Verdigrife.	Unknown.	Sugar of Lead.	Little known.

The foregoing two tables shew the combinations which produce many of the best known salts. In each line opposite the acid, is written the name of the salt, which is produced by combining it with the base, which is placed at the head of the column. For example, the marine acid combined with the base volatile alkali, produces sal ammoniac; and so of others. Brevity has made it necessary to omit a considerable number of acids, and also several metals, together with all the semi-metals; the respective combinations of which would have been very interesting in a more extensive work. For the same reason, we cannot enter into a detail of the methods by which the combinations here set down are made. It will also be observed, in looking over the tables, that the account of most of the salts has been anticipated in the foregoing part of the present section. We shall only therefore describe the methods by which the mineral salts that furnish the three principal acids are procured. Vitriol has already been adverted to: nitre and sea-salt remain to be spoken of.

Nitre

Nitre is peculiar in the circumstance of its never being found ready formed, as is the case with vitriol and sea-salt, but is produced, by a concurrence of circumstances, in bodies which originally do not contain it. These substances, with respect to the nitre, are called nitre beds.

It is said, that small crystals of nitre are naturally formed on the surface of the ground, in Pegu, Bengal, and some places on the coast of Africa after the rains. Several plants, for example, turnsole, are found to contain nitre ready formed; but as the quantity is very unequal in plants equally vivid and flourishing, and sometimes none at all, it is justly thought to be extraneous to them, and dependant on the soil. There are fields in Spain which have immemorially furnished nitre, without any particular culture for that purpose. And universally, the earth of stables, pigeon-houses, cellars, barns, mud-walls, and the mortar of all covered damp places, or inhabited buildings, are found, after a certain length of time, to contain nitre.

The result of observation on this subject, is, that nitre is never found but in

earths, which have been accessible to vegetable or animal putrefactive matter, and that the putrefaction must have been complete. If vegetable matter be united with the earth, proper nitre, with basis of vegetable alkali is in general produced; but if animal matter, the nitre is in greater quantity, but almost always with an earthy basis. The best nitre beds are such as consist chiefly of calcareous earths, which probably arises from their porosity, by which the access of air, which is necessary to complete putrefaction, is promoted.

It is therefore undetermined from whence the nitre, or rather the nitrous acid, proceeds: whether the animal and vegetable acids are converted by putrefaction, or whether an acid from the air attaches itself to the putrefactive matter. From very late experiments, there is reason to believe, that pure air itself is the nitrous acid in a peculiar and permanently elastic state.

To extract nitre from the earth in which it is contained, the whole mass is put into a large vessel, and water poured upon it, which, after some hours, is drained away by a perforation at the bottom of the vessel. This
impreg-

impregnated water is then boiled till it becomes much concentrated, after which, it is poured upon wood-ashes in another vessel. By this last operation, the nitre, with an earthy basis, is decompounded, and receives a basis of fixed vegetable alkali from the ashes. The lixivium being drained off, is again boiled, by which means a great part of the common salt usually found in nitre earths, crystallizes and is taken out, and the nitre itself crystallizes, when the liquor is removed into proper vessels, and cooled. It is farther purified by solution in a fresh quantity of water, as has already been observed in the course of the present chapter.

There is nothing intricate or difficult in this process, for extracting nitre from the earth in which it is generated; and therefore, it is not very strictly followed by the makers. Some mix the ashes with the rubbish or earth, and boil the lixivium but once; and, indeed, this seems to produce a saving, both of labour and fuel. And in India and Spain, it is said, that the nitre is procured without the use of wood-ashes. The fixed alkali is probably furnished by the

X 2

plants

plants which have putrefied on the surface of the earth in those warm countries; but it may be justly suspected, that they lose a considerable quantity of nitre, which, having an earthy base, might have been converted into true nitre, by the use of the vegetable alkali of wood-ashes.

Nitre may be melted, and even made red hot, for a short time, without any considerable dissipation of its acid, or other change; but if any substance containing phlogiston be brought into contact with nitre, either of the two matters being heated to ignition, a very singular and remarkable phenomenon, called detonation, takes place. The acid combines with the phlogiston, and is suddenly dissipated into air with noise and flame, and the alkali is left in a state of considerable purity, but combined with fixed air. Detonation is peculiar to those saline matters, into the composition of which the nitrous acid enters; and in general, those salts whose bases attract the acid most strongly, possess this property in the greatest degree.

Nitrous ammoniac, and several metallic nitres will detonate to a certain degree by
heat

heat alone, without the addition of any other body. This property must be attributed to the phlogiston contained in their bases.

The detonation of nitre is not well understood, but it seems to be analogous to the inflammation of oils by the nitrous acid, and probably depends on the strong affinity between that acid and phlogiston. If a piece of red hot charcoal be plunged in the nitrous acid, it is quenched with scarce any detonation, the acid not being sufficiently concentrated in its fluid state to produce the effect. But in nitre, the acid is in a very high state of dephlegmation; being combined with the alkali, which may answer much the same purpose as the admixture of vitriolic acid in the inflammation of oils. And if this be true, the degree of concentration may be greatest in such nitrous salts, as possess the most attractive bases with respect to the acid; and consequently in these, the detonation must be the most violent.

The great quantity of permanently elastic vapour, which is produced by the detonation of nitre, renders it necessary for chemical operators to be very cautious in the manage-

ment of their processes with this salt: for if the production be very quick, the vessels will burst with a great and dangerous explosion. The detonation depends on the contact between the nitre and the phlogistic substance. If the surface of contact be extensive, the decomposition must be more rapid and sudden; and contrariwise, if the surface be less, the detonation will last longer, and be less violent. Thus, if a lump of charcoal be thrown into a small crucible, containing ignited nitre, a vivid and fierce flame will surround the charcoal, and the decomposition will proceed gradually; but if, by pulverizing, the same piece of charcoal be made to present a much larger surface, and it be then added to the heated nitre, the effects will all be much more strong and sudden. The danger of explosion is therefore in some respect diminished, by avoiding a too intimate mixture of the nitre with those substances which might afford phlogiston.

But in the making of gunpowder every circumstance that can promote the sudden detonation is carefully attended to. Gunpowder is a composition of nitre, charcoal
and

and sulphur. The first of these is that on which its efficacy depends; the charcoal affords phlogiston, and the sulphur renders the mass inflammable at the slightest touch of an ignited body. In the manufacturing, it is of much more consequence that the ingredients be intimately mixed, than that the proportions be strictly accurate. One hundred pounds of English gunpowder is said to contain 75 lb. of nitre, 15 lb. of sulphur, and 10 lb. of charcoal. These are mixed by continual kneading with water in wooden mortars, with wooden pestles, whose motion is produced by a mill. After the mixture is made, this paste is rubbed through the holes of a wire-sieve, by which it is cut into small masses or grains, which, for musquetry, are afterwards smoothed, or, as it is termed, glazed, by their mutual friction against each other in a barrel, mounted on an axis for that purpose. Lastly, the powder is rendered as dry as possible, by means of heated stoves, so contrived, as to avoid the danger of explosion. The effects of gunpowder are very much augmented by its granulation; for if a gun be charged with ungrained powder, the fire will be successively

communicated ; that is to say, those parts which are far from the touch-hole will not be inflamed till the parts situated nearer are first burnt, and exploded : by which means a great quantity of the powder must be blown out of the piece without exerting its force. But when the powder is granulated, the explosion of the first small quantity communicates its flame through the empty spaces between the grains, and fires the whole almost at the same instant. No wonder then that the effect in this latter case should be prodigiously greater.

Common salt is extracted from mines in the earth, and is then called *sal gemmæ*, or rock-salt. There are also many springs which furnish this salt, probably from their passing through mines in which it is contained. And the ocean is every where impregnated with about one-thirtieth of its weight of salt. From these several sources it is obtained for culinary, and other purposes. In Italy, Spain, and the south of France, a strong, though impure, salt is obtained from sea-water, by receiving it into large sluices or reservoirs, and suffering it to evaporate by the heat of the Sun,

Sun, till crystals are produced. This is called bay-salt. In England salt is procured mostly by boiling either the salt-water of the sea, or brine-springs, in both which they usually dissolve rock-salt. The use of crude rock-salt is prohibited in England; and therefore it is always purified for home consumption by solution and crystallization. A part of the acid of sea-salt is driven off by heat, from which circumstance it happens, that purified salt is always stronger and more pungent the less heat is employed to evaporate the water.

The following table of affinities needs no other explanation than observing, that the affinity of any substance to that which stands at the head of the column is greater than that of any other which stands beneath it. Thus, the affinity of phlogiston to vitriolic acid is greater than that of fixed alkali; and the respective affinities of the other bodies to the same acid, proceeding down the column, are less and less.

TABLE of AFFINITIES.

VITRIOLIC ACID.	NITROUS ACID.	MARINE ACID.	ACETOUS ACID.	FIXED ALKALI.	VOLATILE ALKALI.	AQUA REGIA.	SULPHUR	LIVER of SULPHUR	VITRIF. EARTH.	CALCAR. EARTH.	MERCURY.
Phlogiston.	Phlogiston.	Phlogiston.	Phlogiston.	Phlogiston.	Phlogiston.	Phlogiston.	F. Alkali.	Gold.	L. of Sulph.	IV. Acid.	Gold.
F. Alkali.	Zinc.	Zinc.	Zinc.	V. Acid.	V. Acid.	Zinc.	Iron.	Silver.	F. Alkali.	N. Acid.	Silver.
V. Alkali.	Iron.	Iron.	Iron.	N. Acid.	N. Acid.	Iron.	Copper.	Iron.	Borax.	M. Acid.	Bismuth.
Abf. Earths.	Cobalt.	Copper.	Copper.	M. Acid.	M. Acid.	Cobalt.	Tin.	Copper.	Calx of lead.	A. Acid.	Zinc.
Zinc.	Copper.	Tin.	Lead.	A. Acid.	A. Acid.	Copper.	Lead.	Lead.	Calx Antim.	L. Sulphur.	Tin.
Iron.	Bismuth.	Lead.	Bismuth.	Zinc.	Zinc.	Tin.	Silver.	Tin.		F. Alkali.	Lead.
Copper.	Lead.	Bismuth.		Iron.	Iron.	Arsenic.	Bismuth.	R. Antim.		Borax.	Copper.
Silver.	Mercury.	R. Antim.		Copper.	Copper.	Bismuth.	R. Antim.	Bismuth.		C. of Lead.	R. Antim.
Tin.	R. Antim.	Mercury.		Lead.	Bismuth.	Mercury.	Mercury.	Zinc.		C. of Antim.	
Lead.	Silver.	Arsenic.		Tin.	Mercury.	Lead.	Arsenic.	Cobalt.			
Mercury.	Arsenic.			R. Antim.	Silver.	R. Antim.	Cobalt.				
Bismuth.	Tin.			Cobalt.	Gold.	Gold.					
R. Antim.				Arsenic.							
Arsenic.				Bismuth.							

C H A P. XIII.

Of Magnetism.

THAT remarkable property which iron possesses, of becoming magnetical, seems to stand alone among natural phenomena. It is the only instance of permanent attraction which is sufficiently strong to become the object of vulgar attention ; and philosophers observe its effects with surprise and admiration, while the most cautious and rational are obliged to confess that the cause is entirely unknown.

A strait bar of iron, which in these parts of the world has stood a long time in a vertical position, is found to have acquired the property of attracting other iron at its extremities ; and, if supported in a small vessel, so as to float at liberty upon water, conforms itself to a direction nearly in the plane of the meridian ; the end, which during its perpendicular situation was downwards, always pointing towards the North. This bar is said to be

3 magnetical ;

magnetical; and the unknown cause of these and other concomitant effects is called magnetism.

Magnetism may be given to iron, or rather steel, by many methods, some of which we are about to mention. The disposition to conform to the plane of the meridian is called polarity, and is of such importance in its application, that the modern art of navigation could not exist without it. The mariner's compass is thus constructed. A flat thin bar of steel, rendered magnetical, is fastened underneath a circular card, (fig. 117.) so that the direction of its length may correspond with the line NS. This bar is perforated in the middle; and in the perforation is fixed a brass cap, hollowed out conically, which consequently is in the center of the card. The card thus provided with a magnetical bar, is then supported horizontally, by placing the cavity of the cap on an upright metallic point, and is therefore at liberty to revolve into any horizontal position. But the bar, which is usually termed the needle, conforming itself to the meridian, causes the fleur de lis of the card to point to the North; consequently,

frequently, the other divisions must denote the respective bearings of the points of the compass. This card being thus suspended in a hollow box, and defended from the wind by a pane of glass, with the addition of a contrivance to prevent the effects of the agitation of the ship, is the mariner's compass; by the help of which vessels are enabled to steer their course with safety in the darkest night, and at any distance from shore.

A light magnetical bar suspended in this manner is very serviceable for indicating the magnetism of other pieces of iron. For a bar of this nature will be sensibly moved by the action of another magnetical bar, whose power is too weak to be rendered perceptible any other way.

The ends of a simple magnetical bar are called its poles; and that pole, which, when at liberty, would point to the North, is called the North pole, and the other is called the South pole.

Universally, in two magnetical bodies or magnets, a strong attractive force obtains between the North pole of one, and the South pole of the other, and a repulsive force obtains

tains between poles of the same name. But the repulsive force which exists between poles of like names, is most commonly, and perhaps universally, changed into attraction, when the distance is sufficiently small. From these criterions it is easy to determine the names of the poles of a magnetical bar, by applying it near the suspended magnet, whose poles are known.

If a bar of iron, which is not magnetical, be held in a vertical position, its lower point becomes a North, and its upper a South pole; and these poles may be reversed instantly, and as often as required, by reversing the position of the ends; for the lower will always be North, and the upper South. But a few smart strokes with a hammer at the upper end will fix the poles in their last position, so that after the reversing it the hammered end will still continue to be south, though lowest. Yet, the magnetical power is much the greatest when the hammered end is uppermost, and the effect of the hammering disappears in a few hours.

A bar of iron being suspended on an axis, in a very nice equilibrium, the North end preponderates

ponderates when the bar is rendered magnetical, so that it becomes inclined to the horizon in an angle of about seventy degrees in these latitudes. This is called the dip, and decreases in places more to the southward, and even becomes inverted in places situated considerably on the other side of the equator. The bar thus suspended is termed the dipping-needle.

Magnetism may be given to a bar of iron, by placing it firm in the position of the dipping-needle, and rubbing it hard all one way with a polished steel-instrument. Iron also becomes magnetical by ignition, and quenching it in water in the position of the dipping-needle.

The touch of a magnet communicates the like virtue to other iron, but the quantity or degree which the same magnet can communicate, depends greatly upon the manner in which the touch is performed. If two equal, straight and uniform magnetical bars, with flat ends, be placed together endwise, the contrary poles touching each other, they will form one single magnet, and will communicate a strong degree of magnetism to another bar by
the

the following process: let the last mentioned bar be laid in the direction of the magnetical meridian, and let the others, each of which ought to be at least as long as the bar to be impregnated, be laid upon it in their conjoined state, so that the place of junction may be over the middle of its length, and their poles in the proper direction. Then separate the two magnets, by drawing them asunder along the surface of the bar, and continue to separate them till their ends are at a considerable distance from its ends. Join them again without altering the situation of their poles, by a circular motion of the hand, so that they may meet at some distance above the center of the bar, and lay them again upon it as before. Repeat this operation on both sides of the bar till it has acquired a sufficient degree of magnetism. The maximum is generally obtained after twelve or fourteen strokes.

A bar of iron receives the touch more strongly when it is supported by, or in contact with, another much larger; and a combination of magnetical bars will produce a much greater effect than a single one. Soft
steel

steel acquires the magnetical power more readily, but does not preserve it so long as hard steel. On these, and other considerations, experiments have been multiplied, and various methods invented of giving to steel the utmost degree of magnetism it is capable of receiving. For example, six bars of steel may be rendered slightly magnetical, by affixing each successively to a poker, and stroking it several times from bottom to top with the lower end of a pair of tongs; care being taken to keep both the poker and tongs in a vertical position. For, these utensils, by long standing in a vertical position, are almost always possessed of a fixed magnetism; the lower ends being North poles. Now, if four of the six bars be united into a thick compound bar, the magnetism of the remaining two may be greatly increased by touching with it. These two bars may then be substituted in the room of the two outermost in the compound bar, which will become more powerful by the exchange, and the two which were taken from the compound bar may be touched in their turn. Thus, by reiterated changes, and touching, the bars will at length acquire as

much magnetism as they are susceptible of receiving.

The force of magnetism is exerted through all substances, iron excepted, and it has not been observed, that it suffers the least diminution by the interposition of any foreign matter. Magnetism is destroyed by ignition; and a heated bar of iron is not attracted by the magnet till it is just upon the point of losing its redness.

The loadstone is a ponderous ore of iron, usually of a dirty black color, and hard enough to emit sparks with steel. It is found in most parts of the world, and possesses a natural magnetism, acquired most probably from its situation or position with respect to the earth. This magnetism may be, as it were, concentrated, and made to act much more strongly by covering its polar extremities with steel. The steel thus applied is termed the armour of the loadstone, and requires some management, as to figure and thickness, to produce the greatest possible effect. Formerly all magnetism was originally obtained by communication from the loadstone, but at present the power of steel-bars, impregnated by artificial

ficial means, so much exceeds that of the natural stone, that this latter is little esteemed, except as a matter of curiosity. The magnetism of the loadstone is in all respects similar to that of a bar of iron or steel.

The attraction or repulsion of two magnets decreases as the distance increases, but not according to any ratio of the distance. On this account a magnetical bar, which is at liberty to assume any horizontal position; as, for example, a needle floated on water by means of cork, or the needle of a mariner's compass, being brought into the vicinity of another magnet, will assume such a situation as shall respectively satisfy the attractive and repulsive powers as much as possible. Thus, if a suspended magnetical needle be brought near another magnet, it will place itself in a position parallel to the axis of the magnet, if the poles of contrary names in each be mutually equidistant; but if the North pole of the suspended needle be nearer the South pole of the magnet than the two other poles are to each other, its North end will be most attracted, and consequently must incline, so that the axes of the two magnets will form an angle greater

or less according to circumstances. Suppose now a small magnetical bar, suspended so as to be capable of assuming any position whatsoever, be placed upon, or near the surface of a very large globular magnet. It is evident, in this case, that the two ends of the small bar, being respectively attracted by the contrary poles of the globe, will always be found in the plane of a flat surface passing through those poles: or, in other words, if circles or meridians be supposed to be described on the globe, intersecting each other in those poles, the magnetical bar must always be in the plane of one of them. But its situation with regard to the spherical surface will be governed by the excess of attraction in the nearest pole. If the bar be suspended immediately over the North pole of the magnet, it must stand perpendicularly, with its South end downwards; but if it be gradually removed along the surface, towards the South pole, the increasing action of this last pole will cause it gradually to incline that way. At the equator it will rest parallel to the surface; and in approaching still nearer, its North end will incline towards the surface till at length it will

will stand perpendicularly over the South pole of the great magnet, with its North end downwards. For the sake of conciseness, the poles of the great magnet are supposed to be equally strong; which, however, is seldom the case in reality.

This reasoning may be exemplified by placing a small piece of sewing-needle on the surface of a spherical magnet or loadstone. Its position is found to vary according to its situation with respect to the poles. For the same reasons, steel-filings gently dusted through a rag upon a magnet adhere to it in a very curious and amusing manner. The filings, acquiring magnetism by the contact, adhere together, and form a number of small magnets, which arrange themselves in conformity to the attractions of the poles of the original magnet.

From observations of this nature, it was very early supposed, that the globe of the Earth acts as a large magnet upon all other magnets: whence they naturally tend to conform to the meridian or line which joins the poles of the Earth. And the dipping of the needle is readily explained to arise from the

Y 3 vicinity

vicinity and consequent stronger attraction of the pole towards which the inclination is made. The needle of the mariner's compass varies from the true direction of North and South. The angle formed between the magnetical axis of the needle and the meridian of a given place is called the variation of the compass, and differs in different places both in quantity and direction of the needle. From the phenomena of the variation it is proved, that the magnetic poles of the Earth must be more in number than two, and that they do not coincide with the poles about which the diurnal rotation is performed.

The variation of the compass does not continue fixed and unalterable at a given place. Thus, at the Cape of Good Hope in Africa, near which, at its first discovery by the Portuguese, there was no variation; the North point of the compass in 1622 varied about 2° . to the westward; in 1675 it varied 8° . W. in 1700 about 11° . W. in 1756 about 18° . W. and in 1774 about $21\frac{1}{2}^{\circ}$. W. Regular, though very different mutations have been observed in almost every other place on the globe. The needle of the compass is likewise subject to a
small

small diurnal change of position, and is sometimes considerably agitated during the appearance of the *aurora borealis*.

The observations which relate to the magnetism of the Earth have not been continued long enough to afford a foundation for a good theory. Dr. Halley's hypothesis, though formed near a century ago, still remains the only one which seems at all adapted to the phenomena. He supposes the Earth to consist of two distinct parts, an external shell, or hollow sphere, and an internal nucleus or globe, loose and detached in the cavity, having the same center of gravity with the external part. Each of these parts he regards as a separate magnet, endued with two poles, their magnetical axes not being coincident. A compass-needle on the external surface must therefore be acted upon, as if by a magnet with four poles. From the phenomena he determines the situation of the several poles; and thus explains the variation. But as the variation changes in process of time at any given place, it follows, that these poles do not keep the same position with respect to the surface of the Earth, and to each other. This movement

he accounts for, by supposing that the diurnal motion of the Earth was impressed from without, and that the velocity of the internal part, or nucleus, is somewhat less than that of the external part, or shell. Consequently the nucleus must seem to revolve slowly to the westward, and its poles must describe lesser circles about the poles of the Earth. And as the relative position of the four magnetical poles to each other, and to the poles of the Earth, is changed, so must likewise the direction of the needle, or the angle it makes with the meridian, be altered.

Thus, a kind of regularity prevails in the increase and decrease of the variation, and also the direction of the variation which ships observe as they sail to various parts of the ocean. In the Atlantic ocean to the North, and eastward, and all over the Indian ocean, except in the bay of Bengal, a westerly variation obtains; but to the westward of a certain line, at which there is no variation, all along the coast of South America, and in the Pacific ocean, as far as the 140th degree of west longitude, an easterly variation is observed; and in the whole Pacific ocean besides, the

variation is probably to the west, unless we may conjecture that an easterly variation may be found in the regions to the northward.

When the variation changes quickly in running upon a parallel, as is the case in the southern Atlantic, and great part of the Indian ocean, the longitude may be determined with a considerable degree of correctness at sea. The author of this treatise knows from experience, that the magnetic azimuth of the Sun may be easily observed in moderate weather to the certainty of a less error than ten minutes of a degree : and the true azimuth is obtained from the Sun's altitude, taken at the same time by an assistant. Their difference is the variation. Now, on the parallel of 36° . South, for example, the variation changes $30'$. for every degree of longitude : the observer, therefore, who knows the quantity of the variation within one-third of that quantity, can, by means of a chart of the variations, discover his longitude to less than one-third of a degree ; which, upon that parallel, is equal to no more than the inconsiderable error of five leagues. But the great impediment to this method is the want of a chart ; for
the

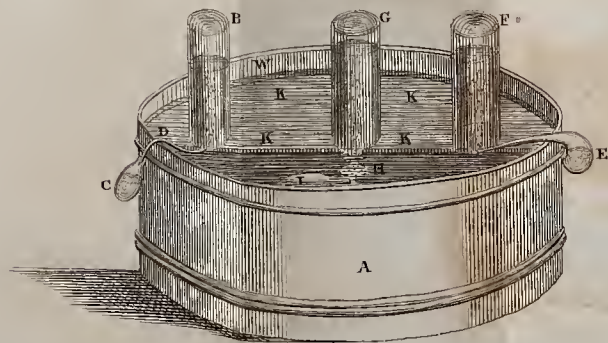
330 *Variation Charts are not encouraged.*

the continual change of the variation makes it necessary that it should be renewed at the end of every three or four years. This short time of sale cannot possibly repay the charges of the compiler. Individuals are therefore deterred from engaging in a labor, which, though beneficial to society, cannot fail of being attended with loss to themselves.

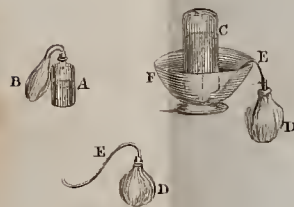


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Apparatus for making Experiments on Air Fig. 134, p.332.



*Impregnation of water with fixed Air:
Fig. 135, p.347.*



*Impregnation of water with
fixed Air.*

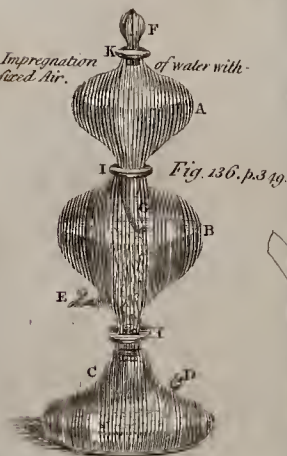


Fig. 136, p.349.

*Endiometer
Fig. 138, p.357.*

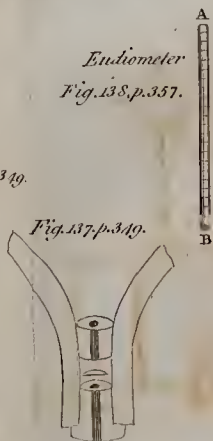
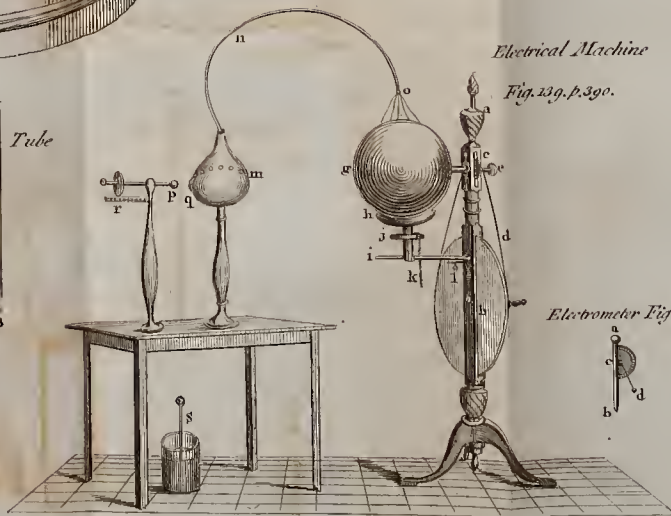


Fig. 137, p.349.

Electrical Machine

Fig. 139, p.390.



Electrometer Fig. 140



B O O K III.

S E C T. II.

Of Air.

TILL very lately air has always been considered as an elementary and simple substance, and no one attempted to analyse it: and in chemical researches that elastic and invisible fluid which escapes during fermentation and solution, and which in distillation renders it necessary to perforate the receiver, in order to prevent the explosion of the vessels, has been scarcely, if at all, examined into. But at present every elastic fluid or vapor, which can be obtained in such a situation as to preserve its elasticity without any considerable diminution by cold, is called air. Vapor, therefore, is an elastic fluid, which may be condensed into a palpable substance by cold, but air cannot be deprived of its elasticity but by combination.

C H A P.

C H A P. I.

*Of the Method of making Experiments ; and
of respirable Air.*

THE most convenient method of preserving the various kinds of air from communicating with the external air is, to make use of glass-vessels, whose mouths are immersed in water, or some other fluid. Let A (fig. 134.) represent a tub ; KKKK is a shelf fixed within, for the purpose of supporting the inverted glass-vessels. Water is poured in the tub to the height W. When it is required to fill a jar either wholly or in part with air, the vessel is filled with water by plunging it in the tub, and then carefully placed on the shelf with its mouth downwards, so that one of its edges may a little overhang the edge of the shelf. By the pressure of the atmosphere the jar continues full of water ; but if another vessel, containing air, be brought underneath, and the mouth of this last vessel turned up, the air will rush out,

out, and rise to the upper part of the jar, expelling an equal bulk of water. Thus, the vessel G being previously filled with water, and inverted, receives the air which is poured out of the bottle I through the funnel H. C is a small crystal-glass bottle, or retort, into the neck of which the bent tube D is fitted by grinding. It contains substances, which, by effervescence or otherwise, produce air. The other end of the tube is inserted under the jar B, into which the factitious air rises, and is preserved for examination. E is a small retort, which is applied to the same purpose as the bottle D. Being formed of green glass, and all in one piece, it is much cheaper, and will bear the application of a greater degree of heat when required. When heat is necessary, a large candle or chafing-dish of coals may be placed underneath the vessel C or D; but if a still greater degree be required than glass can sustain, an iron retort or gun-barrel may be used.

It is proper to observe, that all glass-vessels, which are designed to sustain the sudden application of heat without breaking, ought to be made very thin. It will likewise be useful
to

to the operator to be reminded, that glass-vessels may be readily cleansed from the rust of iron, and other metallic impurities, by previously rinsing them with a small quantity of the marine acid.

If the air, which it is proposed to examine, be of such a nature as to combine readily with water, a smaller apparatus may be made use of, in which quicksilver is substituted. There are also several other contrivances, of which the experimenter may avail himself, by consulting the writings of Dr. Priestley: and there are many particulars which his own observation cannot fail to suggest.

It has long been observed, that the common air of the atmosphere is capable of combining with many substances. From this cause water is held in solution by the air; and rain, snow, or hail, appear to be precipitations which may, perhaps, be caused by the matter of electricity combining with the water, and detaching it from the air, in the same manner as the marine acid precipitates metallic substances from the acid of nitre. As water may be combined with and dissolved in air, so likewise air may be dissolved in water. The affinities of the
different

different kinds of air to other bodies are various, and they are consequently met with in combination, and may, by proper management, be obtained in a detached state.

Common air is diminished in bulk by every process in which phlogiston is said to escape from bodies. Combustion, the calcination of metals, the exhalations of liver of sulphur, white paint, vegetable flowers, and various inflammable matters, putrefaction, respiration of animals, and the electric spark, phlogistificate the atmospheric air. The greatest diminution of air by phlogistication is about one-fourth of the first quantity; and air which is diminished to its utmost by any one process cannot be farther affected by any other. Combustion, the calcination of metals, and the respiration of animals, cannot be performed in phlogisticated air; they therefore cease at a certain period of the process when inclosed in a given quantity of air: if the quantity be greater, the combustion continues longer, a greater quantity of metal may be reduced to a calx, or the death of the inclosed animal is retarded. With regard to the effect of phlogisticated air on animal life, there seems to be
some

some positive action, besides the mere privation of respirable air; for an animal plunged in a vessel of noxious air dies much more suddenly and irrecoverably than in the vacuum of an air-pump.

The combination of phlogiston with respirable air, and its consequent diminution in bulk, might naturally be expected to produce an increase of density. But the contrary appears rather to be the case. This circumstance seems to depend upon a precipitation which takes place of one of the principles of the air. For, if the operation be carried on in lime-water, instead of common water, the lime is precipitated, and upon examination is found to be no longer caustic. The causticity of the lime may be restored by heat, which at the same time expels a considerable quantity of a dense air, which we are to describe under the name of fixed air. It therefore follows, that, during the phlogification of common air, fixed air is precipitated; and consequently that the residue may be either denser or rarer accordingly as the density and other properties of the phlogiston may prevail: but of these properties we know very little. Neither has it

it been determined whether fixed air exists in the atmosphere ready formed, or is produced by a combination which may take place between phlogiston and one of the principles of the atmosphere.

Air diminished by calcination does not precipitate the lime from water. This is pretty well accounted for, by supposing the affinity between fixed air and metallic calces to be greater than between the former and lime or water; the precipitated fixed air therefore must combine with the calx instead of the lime. The increased weight of metallic calces, and the air they are found to contain, afford an additional confirmation of this.

Every species of air may be totally, and almost instantaneously, absorbed by charcoal heated red hot, or, which has been heated red hot, and extinguished, by plunging it in quicksilver, without afterwards exposing it to air. The quantity of air which may be thus absorbed is many times the bulk of the charcoal employed. In order to repeat this experiment, let a jar, partly filled with quicksilver, and partly with any species of air, be inverted into a basin of quicksilver; and let

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pieces of charcoal, which have been previously ignited, and extinguished in the quicksilver, without having been afterwards exposed to air, be slipped under the jar. They will immediately rise to the surface, and come into contact with the included air; part or all of which air, according to its quantity, relatively to the quantity of charcoal, will almost instantaneously disappear.

The noxious quality of air, which has been phlogisticated by respiration, has been ingeniously applied to explain the facts related by travellers, that animals are killed by the breath of whales, and particularly by the breath of an immense serpent that inhabits the banks of the river Amazon. For the air respired by those very large creatures may be sufficient totally to envelope smaller animals, and to exclude the air during a small portion of time, which, however, may be sufficient for this noxious air to produce its fatal effect.

The density or rarity of atmospherical air, within certain limits, is not of so much consequence to respiration as might be imagined. For the air at the summits of mountains is frequently not more than half the mean density

sity of the air at the level of the sea, but is nevertheless breathed without inconvenience. And Dr. Halley remained an hour and an half at the bottom of the sea in the diving-bell, without any ill consequence, at the depth of ten fathom, care being taken to renew the air. Now, the pressure of ten fathom of sea-water is almost equal to that of two atmospheres, and consequently the air in that situation must have been compressed into one third of its original space.

The long exposure of air to the phlogistic emanations in coal mines, and other subterraneous places, and the actual production of noxious air, which is occasioned by the spontaneous processes which are carried on in the bowels of the earth, gives birth to the damps which are so fatal to miners. And since, upon the whole, the daily combustion of fuel, the respiration of animals, and the putrefaction of animal and vegetable substances, must continually vitiate a great quantity of air, it is of consequence to enquire what provisions there are in nature to counteract a depravity, which would otherwise put an end to the life of every creature on the surface of the earth.

Noxious air is meliorated by agitation in water. It is therefore probable, that the continual circulation of water, by evaporation, which falls again in showers, may contribute much to preserve the purity of the atmosphere. But vegetation is more particularly effectual in this respect. If the fresh leaves of any plant be put into an inverted jar, containing water, and exposed to the direct light of the Sun, they emit a considerable quantity of air, which possesses all the properties of the purest atmospherical air, but in a much higher degree; as is proved from its greater aptitude to promote combustion, and the difficulty of rendering it noxious by any of the processes which injure common air. This is termed dephlogisticated air, and observation evinces, that it is not really produced from the plant, but consists of air which is imbibed in its phlogistic state, and again emitted in a state of purity.

Dephlogisticated air is obtained by exposing either red lead, or the precipitate per se of mercury, to heat; or, by heating any dephlogisticated earth or alkali, which has been previously moistened with the nitrous acid. In
the

the first instances, it is probable that the calces of lead and mercury only gave out that pure air which had before combined with them during their calcination ; but the latter seems to point out the constitution of dephlogisticated air. For the same earth will, by repeated moistening with the nitrous acid, be rendered capable of producing fresh quantities of pure air, till the earth be intirely consumed. It is therefore probable that dephlogisticated air consists of the simplest or elementary earth, combined with an acid in a state of permanently elastic vapor.

Dephlogisticated air may be expelled by heat from almost all the saline combinations of the vitriolic acid. The acid of this air, if the expression may be used, consists then of something which is common both to the nitrous and vitriolic acids, and the earth consists of something which is common to the metalline, calcareous, argillaceous, and alkaline earths. A decomposition of pure air must therefore be an exceedingly interesting phenomenon, since we might thence obtain an acid, or an earth vastly more simple than any substance

to which chemists have given the name of element.

Dr. Priestley, whose industry in this department of natural philosophy has been crowned with peculiar success, has offered a very happy theory of the detonation of nitre. For, since a large quantity of dephlogisticated air is produced from heated nitre, and this air is much more disposed to promote combustion than the less pure air of the atmosphere, it is not to be wondered at, that any inflammable substance brought into contact with nitre sufficiently heated, should be consumed with great violence and ardor. The inflammable substance, by its great heat on the other hand, promotes the conversion of the nitrous acid into air, and the maximum of heat, relatively to the surface of inflamed matter and nitre in mutual contact, is quickly obtained. When that surface is very extensive, as is the case in gunpowder, the great quantity of air, which is almost instantaneously generated, together with the intense heat, must occasion a very strong explosion. The presence of the external air is obviously unnecessary.

Dephlogisticated

Dephlogisticated air is heavier, and phlogisticated air is lighter than the common air of the atmosphere.

C H A P. II.

Of Fixed Air.

IF any native calcareous earth, as chalk, marble, lime-stone, sea-shells; or mild fixed alkali, or magnesia, be exposed to violent heat in a retort, an elastic fluid is expelled, which is improperly termed fixed air. If an acid be added to any of these substances, an ebullition arises, from the escape of this fluid in the form of bubbles. The usual method of obtaining fixed air for experimental purposes, is, by immersing chalk in water, rendered sour by the addition of a small quantity of the vitriolic acid. Calcareous earths in general contain more than one-third of their weight of fixed air.

Fixed air is in the highest degree noxious; immediately extinguishing a candle, and producing almost instantaneous death to the ani-

mal that breathes it. It is heavier than any other kind of air, being in the proportion of 157 to 100 to the weight of atmospheric air, and is readily imbibed in water, to which it communicates an acidulous taste, which is not unpleasant. It does not exhibit many proofs of acidity while in its elastic state, but is, however, sufficiently so to change the color of blue stained paper. The criterion by which it is distinguished is that of combining with, and precipitating the lime contained in lime-water, which by that means is rendered mild, and capable of again effervescing with acids, as has already been explained in speaking of the properties of calcareous earth.

A great quantity of fixed air is emitted by substances in the state of vinous fermentation. It is likewise emitted from bodies while they undergo the putrefactive, and, probably, during the acetous fermentation. The upper part of the large vats in brew-houses, which are partly filled with fermenting liquor, is almost entirely occupied by fixed air, which, on account of its great specific gravity, does not readily escape. It is particularly amusing
to

to make experiments with this large quantity of invisible fluid, whose properties are so different from common air. Candles, or lighted paper, are instantly extinguished by dipping into it; and water in a shallow dish, which is held near the surface of the fermenting liquor, soon becomes impregnated with fixed air, and acquires the sparkling appearance and brisk taste which is observed in some mineral springs. A small quantity of gunpowder being exploded in this atmosphere of fixed air, the smoke diffuses itself without rising out of its confine: and by this means the body of fixed air may be rendered visible, and its upper surface thrown into waves by agitation. But the most striking method of performing experiments with fixed air is, to lade it out by means of vessels, like water, or any other dense fluid. Nothing can be more singular than this action, of pouring from one vessel to another, where nothing appears that is thus poured; and to see, nevertheless, a candle instantly become extinct, an animal die in a few seconds, and an alkali made to crystallize, when they are put into this second jar, which does not seem to contain any thing.

Fixed

Fixed air appears to be a peculiar acid, whose affinity to water is too small to admit of exhibiting it in a dense concentrated form. It seems to pre-exist in calcareous earths, and similar bodies, from which it is obtained, and which may be again restored to a mild state by re-combining with it. But it may, perhaps, be produced by fermentation from bodies in which it did not previously exist as a principle. It may be suspected, that fixed air is the acid part of pure air, combined with phlogiston; for it is abundantly produced by the deflagration of nitre with charcoal; whereas a dephlogisticated air would have been produced if the nitrous acid had been heated with an earth not containing phlogiston. Small portions of fixed air are obtained during the processes for procuring dephlogisticated air.

Several saline substances afford fixed air; and it may, as an acid, be combined with alkaline, earthy, and, perhaps, metallic bases, so as to form neutral salts. It is said that Mr. *Achard* of *Bale* has procured true crystals as hard, and of the same shape as native rock crystals, by applying fixed air in a certain manner, and by a very slow operation to some earthy matter.

A heavy

A heavy and noxious air, which by its properties seems to be fixed air, is found in some caverns, and not unfrequently in mines. The coal-miners call it choke-damp. The Grotto del Cano in Italy is a dry cave, which penetrates about twenty feet into the side of a mountain, and has for ages been covered at the bottom with a stratum of fixed air, which instantly extinguishes candles, and kills animals which hold their heads down. All the sparkling mineral waters contain fixed air, and it is to this fluid that beer, cyder, champagne, and similar liquors, owe their briskness and pungency.

Liquors, containing fixed air, are remarkably antiseptic. The impregnation of water with fixed air is therefore a matter of considerable importance, as it may furnish one of the best remedies for that terrible disorder the scurvy. The cheapest method of performing this is by means of a bladder, in the neck of which is fixed a perforated cork. Fig. 135. A is a bottle, containing the effervescing mixture of chalk, or marble, and water rendered acid by the affusion of oil of vitriol. B is an empty bladder, in the neck of which is

fastened a perforated cork, which in the figure is likewise inserted in the neck of the bottle A. The fixed air generated by the effervescence must therefore pass through the cork, and distend the bladder. While the bladder is thus filling, the operator fills the bottle C with water, and inverts its neck into the basin F, which likewise contains a small quantity of water. This may easily be done without any escape of the water from the bottle, if the neck be closed by means of a card, which may be withdrawn after the immersion. The bladder being filled, must be withdrawn from the bottle A, and a bent tube E inserted in the perforation of the cork, by means of which the fixed air may, by pressing the bladder, be driven into the upper part of C, the displaced water subsiding at the same time into the basin. The tube must now be withdrawn, and the bladder replenished as before, from the bottle A; during which time the bottle C must be agitated, care being taken that its mouth be continually under the surface of the water. By this means the greatest part of the fixed air will be very quickly imbibed by the water, which consequently will

rise

rise into the bottle as before. The operation may be again repeated till the water has imbibed a quantity of fixed air exceeding its own bulk; at which period it will be found to exceed the best Pyrmont water in briskness and pungency.

But the most effectual and elegant method of impregnating water with fixed air is by the apparatus delineated fig. 136. It consists of three glass-vessels; the lower C has two necks, D and H; the former of which is closed with a ground stopper. The second vessel B is fitted into the neck H of the lower vessel by grinding; and in the lower neck of B is a valve, contrived by means of a plano-convex lens, moveable between two perforated-stoppers, as in the large representation, fig. 137. The upper vessel A, which terminates at bottom in a tube G, is likewise fitted by grinding into the neck I of the middle-vessel, and is closed at top by a conical ground stopper F. The effervescing materials are put into the lower vessel C, the middle vessel B is filled with the water to be impregnated, and the whole apparatus is put together as in the drawing.

350 *Impregnation of Water with Fixed Air.*

drawing. The fixed air passes through the valve at H into the upper part of the vessel B, and displaces a quantity of water, which rises through the tube G into the vessel A, the common air in A lifting up the conical stopper F, and escaping. When the water in B has subsided below the orifice of the tube G, it can no longer be impelled into A, but a part of the fixed air rises instead, and by expelling the greatest part of the remainder of the common air, occupies the upper part of the vessel A. Thus, then, the contained water is exposed for a long time to a surface of fixed air, without any communication with the atmosphere. The effervescing materials may be occasionally renewed at the aperture D, and the impregnated water may be tasted or drawn off by the glass cock E. If the vessels be not agitated, it is several hours before the water acquires its utmost impregnation.

The colder the water, provided it be not congealed, and the greater the pressure it sustains, the greater quantity of fixed air may be absorbed. Water gives out its fixed air either by boiling or by being placed in the
vacuum

vacuum of an air-pump. Freezing likewise extricates the fixed air from water, and it gradually escapes by mere exposure to the atmosphere.

C H A P. III.

Of Inflammable Air. Of Nitrous Air, and the Method of discovering the Purity of the Atmosphere.

A SPECIES of air is frequently generated in coal-mines, which is inflammable. It is much lighter than common air, and therefore hovers near the top of the mine, so that a candle may often be carried with safety near the ground, which, if raised to the height of a few feet will burn with an enlarged flame, and sometimes set fire to a vast mass of inflammable air. In this last case the explosion produces very terrible effects.

The air emitted by stirring the mud at the bottom of some standing waters has been found to be inflammable. Putrescent animal matters emit this fluid, as has been observed in church-yards, houses of office, and such like

like places, and the *flatus alvi* of animals is inflammable. The upper part of casks filled with water from the Thames, and several other rivers into which much fermentable matter is washed, contains inflammable air after having remained closed for some months, as is well known to sea-faring people. And the *ignis fatuus*, or Will-with-the-wisp, is thought to be the inflammable air which is emitted from marshy places, and kindled by electricity.

Inflammable air is obtained by distillation from wax, pitch, amber, coals, and many other phlogistic substances; and the quantity produced is much greater when the heat is suddenly applied. The flame, which accompanies combustion in most instances, seems to be produced by the generation and consumption of this fluid. It is not easy in the present state of our knowledge to determine what occasions the difference between inflammable and phlogisticated air. Perhaps the phlogiston in the former may be more weakly united to its base, and therefore be better adapted to form that sudden union with pure air in which combustion seems to consist.

The most convenient method of procuring inflammable air is by the solution of metals. If iron, zinc, or tin, in small pieces, or filings, be covered with a sufficient quantity of diluted vitriolic, or marine acid, in the retort C or E, fig. 134. and a candle be applied to the bottom of the retort, the solution will be made with considerable ebullition, and inflammable air will pass into the jar B or F.

Like all other inflammable matters, this air requires the presence either of pure air, or of nitrous acid, to enable it to burn. Gunpowder may be fired in, or the electric spark may be passed through, a quantity of inflammable air, without producing any considerable alteration; but if the inflammable air be mixed with a certain quantity of common air, an explosion is sure to follow in either case. Judging by the sound of the explosion, an equal part, or rather more, of atmospherical air, is necessary for the instantaneous combustion of the inflammable air. Any considerable deviation from this proportion causes the explosion to be less. If a candle be applied to the mouth of a bottle containing inflammable air, that part which is in the

VOL. II. A a neck,

neck, being mixed with common air, catches fire, and the whole burns silently away, the external air probably maintaining the combustion by rushing into the bottle. But if a mixture of dephlogisticated and inflammable air be fired, the explosion is astonishingly strong.

Inflammable air is instantly fatal to animal life. It is the lightest fluid yet obtained on the surface of the earth in the mean temperature of the atmosphere; being eleven times lighter than common air, or 8800 times lighter than water. Notwithstanding which, its refractive power on the rays of light is rather greater than that of common air.

If the nitrous acid be applied to iron, copper, mercury, silver, bismuth, or nickel, or, in general, to any kind of inflammable substance; or, if aqua regia be applied to gold or regulus of antimony, an elastic fluid is produced, which is known by the name of nitrous air.

A very remarkable phenomenon takes place upon the mixture of nitrous air with the common atmospherical air. Immediately upon their junction, a turbid redness appears, which is accompanied with heat. This is evidently similar

lar to the effervescences of dense fluids; and when it has ceased, the bulk of air is found to be phlogisticated and diminished. The diminution of the whole mixture does not consist of an equal quantity of each kind of air, but the respirable air is diminished about one-fourth, and a quantity of nitrous air disappears, which is necessary to produce that effect. If to a given quantity of common air be added nearly half its bulk of nitrous air, the whole quantity will be diminished to three-fourths of the original bulk of common air, and any farther addition of nitrous air will only produce an equal increase of the bulk without any other effect. But if, on the contrary, a small quantity of common air be added to a larger mass of nitrous air, the whole bulk, after the effervescence, will always be greater than the original bulk of nitrous air. In these experiments it therefore appears, that the diminution of the common air is always a proportional part of its bulk; but that the diminution of the nitrous air bears no relation to its own bulk, but is the absolute subtraction of a quantity which is in proportion to the quantity of common air. It follows consequently, that if

the nitrous air be insufficient, or only equal, to produce the whole diminution, it will entirely disappear; and, if it be in any quantity more than sufficient, the quantity which disappears will nevertheless be in all cases the same. In order then to discover the quantity of the diminution, it is not necessary to employ the precise quantity of nitrous air which is necessary to saturate the common air, but only to add a known quantity which is known to be more than sufficient.

Dr. Priestley having found that this diminution, by means of nitrous air, is of the same nature as its diminution by other methods, has very happily applied it as a test of the salubrity of the different specimens of respirable air. For we have already remarked, that air, which is rendered completely noxious by any one process, cannot be farther diminished by any other; and in the application of this test, he found, that the quantity of the diminution is always greatest in those airs which are the most proper for respiration and combustion; that is to say, the most dephlogisticated. Several instruments have since been invented for the purpose of making extemporaneous

aneous experiments of this nature, and are called eudiometers ; but the original method of the inventor has the advantage of simplicity, and is easily put in practice. To find the purity of the air at any place, nothing more is required than to fill a bottle with water, which being poured out at the given place, is replaced by an equal bulk of air that may be corked up, and carried to any distance. AB, fig. 138. is a glass-tube, closed at A, and open at B. Its surface is graduated into equal parts by a diamond, to any degree of exactness. This being filled with water, and inverted perpendicularly in the tub A, fig. 134. a certain measure of the air to be tried, is poured into it, and an equal measure of nitrous air is afterwards added. By means of the graduations it is easy to determine the quantity of the diminution, which may be known to any degree of exactness, by increasing the length of the tube, and consequently of the divisions relatively to its contents. Dr. Priestley, in speaking of the diminution, expresses himself concisely in integers and decimal parts. Thus, if a mixture of equal measures of nitrous and respirable air, after the

effervescence, be diminished, so as to occupy no more than the space of one measure and one-tenth, he says, the measure of the test is 1.1. But when the air is exceedingly dephlogistigated, he adds a greater quantity of nitrous air.

If the purity, of any given portion of air, be as the diminution it suffers by phlogistigation; and if the quantity of nitrous air required to saturate it be likewise in the same proportion, the purity of air, tried by nitrous air, will always be in the direct proportion of the diminution of the whole mixture, provided the quantity of nitrous air added be more than sufficient to saturate it. That air is the purest which produces the greatest effects during the time of its phlogistigation; namely, that in which, *ceteris paribus*, animals live longest, or the greatest quantity of a combustible body is consumed.

Nitrous air is thought to consist of the nitrous acid, rendered permanently elastic by combination with phlogiston. It seems therefore to differ from inflammable air only in the nature of its acid; and when mixed with common air the phlogiston unites with the latter,

latter. The nitrous acid consequently precipitates in its proper form, occasioning the turbid redness, and communicating an acidity to the water, over which the experiment is repeatedly made.

Nitrous air is perfectly noxious both to animals and vegetables, and is incapable of maintaining combustion. It unites with water, and many other fluids, and produces very curious and interesting appearances, which the limits of this treatise do not permit us to enlarge on. It is antiseptic, and is specifically lighter in a small degree than common air.

C H A P. IV.

Of Vitriolic Acid Air, Marine Acid Air, Vegetable Acid Air, Fluor Acid Air, Alkaline Air, and the Vapor of Nitrous Acid.

THE vitriolic acid, applied to charcoal, oil, or other inflammable substance, may be volatilized by heat, and converted into a noxious air, which is distinguished by the name of vitriolic acid air. This air is readily combined with water, to which it gives the properties of the volatile or sulphureous vitriolic acid. It is necessary therefore, in experiments with this kind of air, to use the apparatus in which quicksilver is substituted instead of water. The method of obtaining the vitriolic acid from sulphur seems to be nothing else than the impregnating water with this kind of air.

It is remarkable, that the concentrated vitriolic acid, which produces vitriolic acid air, when applied to several metals, should, when diluted, produce a very different kind of air from the same metals, namely, inflammable

mable air. It is worth enquiry to discover what the produce would be at an intermediate strength of the acid.

This air is heavier than common air, and extinguishes flame. It dissolves camphor, deprives borax of its water of crystallization, and vitiates common air.

If the marine acid be exposed to heat, it volatilizes in the form of air, not being condensable by mere cold. This termed the marine acid air, and the marine acid is nothing else than water more or less impregnated with it. The cheapest and best method of obtaining this air is by distillation from common salt with the vitriolic acid, as is usual in procuring the marine acid. Common salt being put into the bottle C, fig. 134. a small quantity of vitriolic acid is to be added, which, attaching itself to the alkaline base, disengages the marine acid in form of air. In the open air this acid air appears in the form of white fumes, which, probably, are formed by its combination with the vapors in the atmosphere; but the bent tube D being inserted in the bottle, and its other end beneath a jar filled with quicksilver, the air rises to the
upper

upper part perfectly transparent and clear. In the beginning of this distillation it is not necessary to apply heat.

The marine acid, which is obtained by impregnating water with this air, is much stronger than any which is procured by the usual method of distillation. For, as the process is usually managed, the distillers suffer a very considerable part of the acid to escape in the form of air, for want of applying water with which it might combine. But this error begins to be attended to by chemists.

Marine acid air is heavier than common air, and extinguishes flame. It dissolves ice as rapidly as a hot fire. It decomposes sulphur, white vitriol, alum, and nitre, and therefore seems to be stronger with respect to affinity than the vitriolic and nitrous acids. Perhaps the great affinity between this air and water may neutralize or saturate it so far in its dense state, as to make it seem weaker than those acids. It acts upon most phlogistic substances, and becomes converted into inflammable air. Many fluids imbibe it, and exhibit phenomena which deserve to be considered,

The

The concentrated acetous acid affords an air by heat which extinguishes a candle. In some respects it resembles the vitriolic acid air, but differs from it in several essential particulars.

By distillation with oil of vitriol from the minerals called fluors, but more generally known by the name of *Derbyshire spar*, is obtained an acid air, which may be confined by quicksilver. When hot, it corrodes glass. Its most remarkable property is that of forming a stony film or crust with water. For a great part of this air is readily imbibed by water, at the same time that a stony matter is precipitated, and forms an encrustation on the surface. This encrustation is soon broken by the pressure of the atmosphere, which forces the water upwards into the jar, as the air is diminished by absorption, but the water which rushes through the interstices is immediately covered with a new film; and so on successively till the whole air has intirely disappeared, the water thereby becoming impregnated with a very volatile acid. This air is termed fluor acid air.

Water

Water impregnated repeatedly with this acid, and freed from the earthy crust, being heated, was found to yield air, which, by every examination, appeared to possess all the properties of vitriolic acid air.

For these, and other reasons, Dr. Priestley is induced to think, that the fluor acid is not a particular acid, but is the acid of vitriol, charged with as much phlogiston as is necessary to give it the form of air, and also with much of the earthy matter of the fluor. This air extinguishes a candle.

Volatile alkali may be rarefied into air by heat, which is distinguished by the name of alkaline air. It must here be remembered, that mild or concrete alkali, as containing fixed air, is less proper for the purpose than the caustic alkali. For the sake of cheapness, sal ammoniac and quick-lime flaked, may be put in the retort, and the produce by heat will be the volatile alkali, as has formerly been observed, when speaking of that substance.

Alkaline air readily and copiously combines with water, with which it forms a strong volatile alkaline spirit. It dissolves ice as
quickly

quickly as the most intense heat. A very pleasing effect takes place, if it be mixed with any acid air. The two fluids immediately unite, forming a neutral salt, whose aggregation appears like a white cloud, filling the receiver; and in several instances, when the quantities of each are such as exactly to saturate each other, the whole elastic fluid disappears by the union. With fixed air it forms a concrete salt, in oblong slender crystals; with vitriolic acid air it forms vitriolic ammoniac; and with marine acid air, common sal ammoniac.

Alkaline air is slightly inflammable. The electric spark, taken in alkaline air, produces inflammable air; and the quantity or bulk is three times that of the alkaline air. That a species of air, which is totally soluble in water, should, by the electric spark, be rendered insoluble, together with a very considerable change in its other properties, is a circumstance which well deserves to be enquired into; as its explanation cannot fail to throw great light on the nature of these substances.

There is little reason to doubt but that the nitrous acid might be exhibited alone in the
form

form of air, if any fluid could be discovered by which it might be confined. But the vapor of nitrous acid unites with water and with oils, and corrodes quicksilver. Water impregnated with this vapor is converted into a spirit of nitre, which gradually emits a great quantity of nitrous air. Oils impregnated with it emit phlogisticated air. The vitriolic and marine acids may be impregnated with this acid vapor. The vitriolic acid, when saturated, becomes crystallized, and the fluid part is found to be the nitrous acid. But the marine acid is converted into the best aqua regia, which afforded nitrous air by heat. The impregnated vitriolic acid afforded no air.

We here conclude the present section without attempting to speculate upon a subject, which, though of late years it has been followed with an attention equal to its importance, and has been enriched with many capital discoveries, may still be said to be in embryo. The greatest advantages may be expected to science from an examination of substances in a state of such extreme division as is necessary to produce the form of air. Many
have

have already been obtained, and the numerous labourers at present engaged in this ample, and, till lately, unexplored region of chemistry, encourage us to hope for great things. Prudence and caution ought therefore to correct and guard our imaginations. A few years will probably enable us to look back on the present infancy of our knowledge, and see the futility of those theories which we are too apt to regard as some of the greatest efforts of the understanding.

B O O K III

S E C T. III.

Of Electricity.

C H A P. I.

*Of Electricity ; and the Relations that subsist
between it and different Bodies.*

ELECTRICITY is that branch or department of natural philosophy, in which the appearances occasioned by the motions or action of the electric matter are explained : it is also used to imply the electric matter itself.

The usual method of procuring or exciting electricity is by rubbing a tube or cylinder of glass with the hand, or a rubber of soft leather.

leather. If a tube of an inch and half in diameter, and about three feet long, be rubbed, by drawing the hand, or a rubber of leather, from one end to the other, it will become electric; small flashes of divergent flame, ramified something like trees bare of leaves, will dart into the air from many parts of the external surface of the tube, to the distance of six or eight inches, attended with a crackling noise; and sometimes sparks of more than a foot in length will fly along the tube to the rubber. While the tube is in this state, it attracts light bodies, and immediately afterwards repels them; and does not again attract them until they have touched some non-electric body. If this non-electric body be near the tube, the light body will be alternately attracted and repelled for many vicissitudes. If any non-electric body be presented near the tube, the electric matter will fly, in the form of a spark or ray of fire, from the tube to the non-electric.

With respect to the electric matter, all bodies may be divided into two classes, electrics and non-electrics. Electrics are those bo-

dies, any part of whose surface may be rendered electrical by friction or otherwise, without communicating the same kind of electricity to any other part. Non-electrics are those bodies which cannot be rendered electrical by friction with each other; and if electrified by other means at any part, the whole of the body exhibits the same kind of electricity. The latter are termed conductors. The only unequivocal distinction between these two classes, or at least the strongest and most remarkable, is, that the non-electrics conduct the electric matter through their substance without any sensible resistance, whereas electrics do not conduct. In the usual temperature of the atmosphere, metallic substances, water and charcoal are conductors: all other bodies are non-conductors.

A non-electric, which is supported by electric bodies, is said to be insulated, provided it do not touch the earth, nor any one of a series or set of non-electrics in contact, which touch the earth in any part of the series.

If the excited tube be brought near enough to an insulated conductor to give sparks to it,
the

the conductor will be electrified, and exhibit the same signs of attraction and repulsion ; and if the finger, or any other uninsulated non-electric, be brought near, the conductor will give one strong spark, and lose its electrization. This follows from the nature of a conducting substance ; for when the electric matter leaves the insulated non-electric, it is readily conducted to the place of exit, and therefore escapes all at once ; whereas in the tube, when a spark is drawn, it is much smaller, as consisting only of so much electric matter as is within the striking distance from the finger : this must therefore be repeated at every other part of the tube before the whole of the electric matter can be drawn away.

No experiments have yet been discovered to shew in what particular the difference between electrics and non-electrics consists ; but whatever the conducting power may depend on, it seems to be governed by the heat of the body : glass, resin, baked wood, and many other non-conductors, are conductors when made very hot. Now, as we see like phenomena produced in different bodies with very different degrees of heat,

for example, a fluid state is produced in quick-silver by the least heat, in ice by a greater, in butters, resins, sulphurs, metals, and glass, by degrees still increasing, and very different, why may it not be conjectured, till decisive experiments are exhibited, that the disposition to conduct electricity is produced in metals by the least heat, in water by a greater, and in resins and glass by degrees still greater? and consequently that there is a certain degree of heat at which a given body may be said to be at the medium between perfect conducting, and non-conducting, above which degree it becomes a conductor, and beneath, a non-conductor. If this be allowed, it must follow, that conductors are bodies whose electric or non-conducting state is placed at a degree of heat far below that which is understood by temperate, and that non-conductors are those whose conducting state is placed at a degree of heat far above that of temperate.

That electricity is real matter, and not a mere property, is evident, because it is itself possessed of properties. When it jumps from one body to another, it divides the air, and
puts

puts it into those undulations in which sound consists. It emits the rays of light in every direction, and those rays are variously refrangible, and colorific, as other light is. Now, as light has long been acknowledged to be matter, it is contrary to reason and experience to suppose, that the thing which emits it is not likewise material. Neither are the other senses unaffected at its presence; its smell is strongly phosphoreal or sulphureous, insomuch, that when the air of a room is rendered highly electric, many persons have complained of an unusual and disagreeable sensation in the head from that cause. The sense of feeling is a witness of its presence, not only from the sparks, which, when received from the conductor of a powerful machine, are very pungent, and will pass through two or three persons standing on the ground, but also from the shock, whose effects are to be described: and a stream of the electric matter received on the tongue has an evidently subacid taste, which remains some little time after.

As the exciting a tube is very laborious for the operator, and the electricity procured by

that means is small in quantity, globes or cylinders are much more used. These, by a proper apparatus, are made to revolve on their axes after the manner of a grindstone, and a rubber of leather is applied to the equatorial parts of the revolving glass, which become electrical by the friction. The electricity of the globe is received by a metallic conductor, which is insulated by a glass-foot, or supporter. This conductor being thus constantly electrified, and being at the same time steady and motionless, is much better adapted for making experiments than the globe itself.

A cylinder or globe thus adapted to revolve on its axis, and provided with a rubber and an insulated conductor, is called an electrical machine. The contrivances for the revolution of the cylinder or globe vary in different machines, as likewise the method of insulating the conductor. The conductor is in general supported by a stick of baked wood or glass, and sometimes it is suspended by silk-strings.

C H A P. II.

Of Excitation; of the two different States of Electricity, and of the Effects of pointed Non-electrics.

THE excitation of electrics, rubbed against each other, is very small. To produce any considerable degree of electricity, it is necessary that the rubber should be a conducting substance, and that it should not be insulated,

If the rubber of an electrical machine be insulated, and the conductor uninsulated by hanging on it a chain which communicates with the earth, the rubber will become strongly electric by turning the globe, will attract and repel light bodies, and act in the same manner in almost every particular as the conductor when electrified in the usual method. If of two conductors, separately insulated, one be connected with the insulated rubber, and the other placed near the globe, so as to be electrified by it, they will both exhibit signs of electricity; but that conductor, which is electrified by the globe, will attract those bodies which are

repelled by the other conductor which received its electricity from the rubber. And these conductors, if brought near each other, will emit sparks, and act on each other in every respect stronger than on other bodies. If they be brought into contact, the electricity of the one will destroy that of the other; and notwithstanding the electric matter appears to emanate from the globe to its conductor, the two thus conjoined will exhibit few or no signs of electricity.

We have hitherto spoken of the electric matter as passing from the cylinder to the conductor, but in reality the sense cannot distinguish the direction in which it moves. If it be true, that the electric matter passes from the cylinder to the conductor, the conductor must, when electrified, possess a greater quantity than is natural to it; and since the cylinder is not excited by an insulated rubber, it is evident that it receives its electricity from the rubber, and consequently, unless the rubber be at liberty to receive an equal quantity from the earth, that is, unless it be uninsulated, it can part with but a very small quantity to the cylinder. Still retaining the same supposition
respecting

respecting the course of the electric matter, it follows that the rubber when insulated must lose a part of its natural quantity by friction with the cylinder, and consequently a conductor communicating with it must be negatively electrified. It is not therefore so much to be wondered at, that the actions of the two conductors should be contrary, and that when in contact they should exhibit no signs of electricity; for the cylinder at the same instant that it imparts the electric matter to one conductor, exhausts an equal quantity from the other, which is connected with the rubber. If the direction of the electric matter be supposed to be contrary to what we have assumed, the effects must still be the same.

The circumstance on which the prevailing opinion concerning this direction is founded is, that if the conductor, which derives its electricity from the cylinder, be made sharp or angular at any part, which is not very near the cylinder, a diverging cone of electric light will be seen, whose vertex is the point itself, and the electric phenomena will be much diminished. But the conductor, which

is

is connected with the rubber, though its effects be equally diminished by a similar circumstance, will never exhibit the cone of rays, but is only tipped at the point with a small globular body of light. The cone has been thought to resemble the rushing out or emitting of the electric matter, and the globe has been imagined to answer the appearance of the imbibing or entrance of the same; whence the name of positive electricity has obtained for that of the cylinder, and negative for that of the rubber. We shall use the terms in the same sense, though it must be confessed, that the propriety of their application is still doubtful.

If electricity be produced by the excitation of a globe or cylinder of sulphur or resin; the states will be reversed; the rubber will be positive, and the cylinder, with its conductor, will be negative. This was formerly thought to depend on the nature of the electric body, and the two states of electricity were distinguished by the names of vitreous and resinous electricity, but it has since been discovered, that the difference arises from the relative smoothness of the surfaces of the electric body
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and its rubber when compared with each other.

It seems to be a rule, that the smoothest of the two bodies obtains the positive state. Baked wooden cylinders, with a smooth rubber of oiled silk, become negative, but with a rubber of flannel positive. Glass, made rough by grinding with emery, excited with new soft flannel, is negative, but with dry oiled silk, rubbed with whiting, positive; but if the glass be smeared with tallow, and wiped with a cloth, then the oiled silk, by rubbing, becomes polished, and the tube becomes negative, as at first; if the oiled silk be again rubbed with whiting, it excites a positive state on the greased tube; but when the silk has again acquired a polish, the tube becomes again negative. Even polished glass may be rendered negative by rubbing with the hairy side of a cat's skin.

The rubber in the common electrical machine is usually covered with an amalgama of mercury and tin, and the leather is damped occasionally. These provisions augment the excitation very much. It seems as if the amalgama or metallic rubber, being a perfect conductor

conductor, supplied the cylinder more readily with the electric matter than any other body. The precaution of damping is to keep the rubber more perfectly uninsulated.

It is a maxim, that bodies possessed of similar and equal states of electricity, repel each other; that bodies possessed of opposite states of electricity, attract each other; and that bodies in a mean or natural state are attracted by all electrified bodies whatever. But as we have no clear conception, or adequate idea, of any mechanical process by which attraction may be caused, all our reasoning on the subject must be not only hypothetical, but visionary, for want of probable grounds to proceed on. Yet, if ever we should arrive at an explication of this property of matter, whose origin at present is so little understood, we have great reason to think that it will be in consequence of electrical discoveries.

Speaking of the positive and negative conductors, it was observed that electricity was emitted or imbibed at the angular or pointed parts. It is necessary to advert again to that particular. If the insulated
conductor

conductor of a machine, usually called the prime conductor, be well polished, and without corners or angles, it will retain its electric state very well, and will emit strong sparks upon the approach of any uninsulated conductor. If the uninsulated conductor be broad, round and polished at the end, the sparks will be short and dense, and will produce a considerable sound; if the conductor be less broad, *ceteris manentibus*, the spark will be long, crooked, and less sounding; if the breadth be still more diminished, the conductor begins to come under the denomination of a pointed body, the electric matter passes to it from the prime conductor, thro' a great space of air with a hissing or rustling noise, and in a continual stream: a still greater sharpness enables the electricity to pass over a greater space, but silently, and nothing is seen but a small light upon the point. If a similar point issue from the prime conductor, and the uninsulated conductor be round and polished, the same effects happen in like situations; but if both be pointed, the electricity is more readily discharged: and in all cases the appearance of the electric matter at the point of the

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the prime conductor will be that which is peculiar to its electricity, a large divergent cone if positive, or a small globular light or cone if negative, and the light at the point presented to the prime conductor will be distinctive of the contrary electricity. Whether a pointed conductor be electrified positively or negatively, if the nose be brought near the point during the electrization, a gentle air will be felt blowing from the point, and the sense will be affected with a sulphureous or phosphoreal smell.

The reaction of the force by which the air is put into motion, is exerted on the pointed body. This is shewn by a pleasing experiment with an electrified wire, thus; to the middle of the wire, or rather between two wires that lie in the same line, is affixed a center-cap like those used in sea-compasses, so that the wire may easily be moved on a point in an horizontal direction, as magnetical needles are; and the ends of the wire are pointed and bent contrary ways to point in the direction of the tangent to the circle described by them. Now if this wire thus suspended on a point, be insulated and electrified,

fied, its sharp ends will become luminous, and it will revolve in a direction contrary to that in which its ends are bent; or if it be suspended on an uninsulated point, and brought near the electrified prime conductor, the same effect will follow.

These are the chief phenomena that accompany the electrization of pointed conductors, and are as yet but very imperfectly understood. The facility with which pointed bodies emit or receive the electric matter seems to depend on a circumstance which we have not yet explained, namely the disturbance which the approach of an electrified body makes in the electric matter naturally residing in or near any conductor, before any communication ensues. We shall therefore again advert to the subject of points when we describe that property, and in the mean time it will not be difficult to account for the other appearances on the ground of the matter of fact only, namely, that points do readily emit or imbibe the electric matter.

It may be thought strange that the air should issue *from* an electrified point, whether its electricity be positive or negative. We can

can easily conceive that the issuing out of the electric matter may cause the air to move in the same direction, but it appears strange, that the electric matter rushing towards a point should cause the air to move directly contrary, that is to say, likewise from the point. But if the circumstance be examined more narrowly, the difficulty will vanish. For it is highly probable that the electric matter passes too swiftly to excite any motion in the air but that of sonorous undulation; to which we may add, that, if the electric matter do act on the air to put it in motion, the air must react with an equal force; and therefore that a current of air blown against the course of the electric matter must affect its appearance, by retarding the rays and deflecting those against which it is struck obliquely: the contrary to which is, by experience, known to obtain; for the luminous cones are not sensibly affected by such treatment. The air being thus indifferent as to the motion of the electric matter, its motion may be shewn to depend on the established principles of electricity. The point is electrified either positively or negatively, and the air, immediately

ately opposite and contiguous to the point, must, by the emission or exhaustion of the electric matter, become strongly possessed of an electric state of the same kind with that of the point: it is therefore repelled and replaced by other air which is also electrified and repelled, by which means a constant stream is produced blowing from the point, and that equally whether the electrization be positive or negative. And, as action and reaction are equal and contrary, the point repelling the air must itself also be equally repelled in the contrary direction; whence the horizontal wire above described is turned, and that always one way, namely, contrary to that in which the air is moved, or to the direction of its bent points.

C H A P. III.

Of the Course of the Electric Matter through the common Air, and through Air very much rarefied, with a Description of an Electrical Machine.

TH E air, being a non-conductor, must be classed among electric bodies, and the prime conductor of an electrical machine being surrounded with air retains its electric state much better than it would do without that circumstance. For the electric matter cannot pass to or from the conductor with the same facility as if this impermeable substance were not interposed.

When air is spoken of as impermeable and electric, it must not be understood as being perfectly so, there being perhaps no body in nature that answers that definition, but as being mostly composed of non-conducting parts. There is always moisture enough in the air to restore the natural state to electrified bodies in a few hours. It is likewise perme-

permeable, as all other electrics are, by the force of the electric matter which divides it or separates its parts: when this happens to a solid electric, a hole is made through it.

Long sparks are always crooked in various manners like lightning; the cause of which seems to be, that the electric matter passes through those parts of the air in which the best conductors are found. Indeed there is reason to think that electricity always requires a conductor to enable it to pass from one body to another. For if a glass syphon, whose legs are equal, and respectively more than thirty inches long, be filled with boiling mercury, and the ends inverted into basons likewise containing mercury, a double barometer will be formed whose upper or arched part will be absolutely void of air. Then if one of the basons be insulated and electrified, the electricity will not pass from the mercury in one leg, through the void, to that in the other; but upon admitting a small bubble of air it is immediately seen passing through the vacant space in the form of bright flashes of flames. In the vacuum of the air-pump the electric matter will pass and appear luminous

between conductors, how distant soever, forming a beautiful appearance, that very much resembles the northern lights or aurora-borealis. It seems, on consideration of these circumstances, that the electric matter could not pass through the absolute void, for want of a conductor, but that the conducting part of the air introduced, answered the purpose, while the resistance of the electric part, being very small, on account of the rarefaction, suffered it to pass from one conductor to another through much greater spaces than it can pass through in the open air.

This opinion is somewhat more confirmed by the observation that the electric matter forces conducting bodies into its path. If a drop of water be laid on the prime conductor, very long sparks may be drawn from it, the drop will assume a pointed or conical shape, and wet bodies which are held near it: a proof that the water is thrown off. If the same experiment be made with melted sealing-wax, the appearance is very peculiar and amusing. The sealing-wax must be dropped on or stuck to the side of the prime conductor, and afterwards melted with a candle; then if
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the conductor be positively electrified, the drop of wax becomes pointed and shoots an almost invisibly fine thread into the air to the distance of more than a yard. This thread is electrical, and would probably be longer, were it not for the sudden cooling of the wax. Whether the same effect would follow on negative electrization is worth the enquiry, but the want of a convenient and strong negative power has prevented the writer of this work from trying it. It is observable that the long sparks abovementioned, with the drops of water, are not seen when the drop is negatively electrified, a light only appearing at the point of the drop. But as the methods used in the experiment did not produce a negative state as strong as the positive one, the constancy of the effect requires to be confirmed by more favorable experiments. Thus much is fact, that the same drop of water which when laid on a cylinder of metal, and connected with the positive prime conductor, emitted sparks five or six inches long, did not produce the least spark when uninsulated and held near the prime conductor, but drew off the electricity exactly as a metallic point would have done.

Thus much of the properties of electric and non-electric bodies being premised, we shall be able to give an intelligible account of the construction of the electrical machine. As the forms of glass cylinders, globes or spheroids, the mechanism by which their rotation is effected, the position, shape and matter of the rubber, and the form and mode of insulating the prime conductor, are all susceptible of great variations, so the construction of electric machines has been very different, according to the views and opinions of the makers.

The best and most elegant machine (fig. 139.) consists of a pillar of mahogany, a, standing upright on three feet. This pillar divides in two places, to receive a wheel, b, in the lower part of it, and in the upper part a pulley, c, which is turned by a leathern strap, d, tightened by means of a small buckle. In the center of the pulley is a strong iron spindle, turning in two firm brass sockets fastened to the pillar. In one of the sockets the extremity of the spindle turns upon a center, by means of a piece of iron, e, screwed into it, while the other is held tight by a brass clasp,

clasp, which may be made to hold it closer, or more loosely, at pleasure, by means of a screw. The iron spindle is made hollow, in the form of a parallelopiped, in order to receive a piece of brass or iron, in which the brass cap that holds the globe, g, terminates. These are exactly fitted to one another, and by this means any globe may be taken out, and another put into the machine, with very little trouble, if these parts be always made to the same pattern.

The globe has its neck cemented into a brass cap, which terminates in a square piece of iron as abovementioned.

The rubber, h, consists of a hollow piece of copper, filled with horse-hair and covered with basil leather. This is again covered with dry oiled silk, which is sewed to that edge of the leather towards which the parts of the globe move in revolving. Towards the other edge the silk is considerably longer than is necessary to cover the rubber, and that part of the silk which covers the rubber is to be rubbed with the amalgama of tin and mercury, mixed with a small quantity of bees-wax and tallow. The use of that part of the

silk which hangs out beyond the surface of the rubber, is to prevent the electric matter from returning back to the rubber along the surface of the globe: for when the globe is excited, this pendant silk is attracted and adheres closely to its surface, and prevents those returning sparks and coruscations which are continually emanating from, and diminishing the electricity of a naked globe. The effects seem to be more than twice as great by the use of this contrivance. The rubber is supported by a socket which receives the cylindrical axis of a round and flat piece of baked wood or glass, *j*, the opposite part of which is inserted into the socket of a steel spring, *i*. These parts are easily separated, so that the rubber, or the piece of wood or glass which serves to insulate it, may be changed at pleasure. The rubber may be uninsulated by means of the chain *k*, which forms a communication between it and the spring; and the spring may be made to press more or less by the screw *l*. It may also be raised higher or lower, to suit globes of different sizes, by means of a contrivance not represented in the plate.

The prime conductor, m, is a hollow vessel, of polished copper, in the form of a pear, supported by a pillar, and a firm basis of baked wood, and receives its electricity by means of a long arched wire or rod of very soft brass, n, easily bent into any shape, and raised higher, or let lower, as the globe may require. It is terminated by an open ring, in which are hung some sharp pointed wires, o, playing lightly on the globe when it is in motion. The body of the conductor is furnished with holes and sockets, for the insertion of metallic rods, to convey the electricity wherever it is wanted, and for many other purposes convenient in a course of experiments. The peculiar shape of this conductor renders it the most capable of retaining its electric state; for, in the common conductors, which are cylinders, with hemispherical ends, the electricity has a greater tendency to escape at the part which is most distant * from that at which it receives its electric state: this therefore, being more obtuse at the most distant part, is less disposed to emit or imbibe the electric matter at

* Or rather, perhaps, from the excited globe.

that part; and consequently, the disposition arising from the figure being contrary to that which is produced by the situation, it becomes as little disposed to part with its electric state by that part as by any other. And if the generating curve be properly adapted, the nitency of the electric matter to influx or emission must be equal at every point of the surface. The electromer, *rp*, was invented by Mr. Lane. It consists of a ball, *p*, which, by means of a wire, whose surface is cut into a fine series, and is inserted through the head of a pillar of conducting matter, is carried nearer to or farther from the prime conductor, and serves to measure the distance to which sparks are emitted. This distance is shewn by the divisions on the plate *r*.

When negative electricity is desired, the chain *k* must be removed from the rubber, and hung upon the prime conductor, so as to connect it with the table; and a short brass-rod, with a knob at the end of it, must be screwed into a small socket in the rubber, above the plate of baked wood or glass. The brass-rod will then serve for a negative prime conductor; for, in this situation,

tion, when the wheel of the machine is turned, this rod being insulated, together with the rubber, through which all the electricity passes to the globe, will receive sparks from any uninsulated non-electric which is presented to it, and therefore electrify negatively.

C H A P. IV.

Of the Electricity which is produced by bringing a Conductor near the electrified Prime Conductor; and of charging and discharging Electric Plates.

IF an insulated conductor, which is free from points, be brought within a certain distance of the prime conductor in an electric state, it will also exhibit signs of electricity of the same kind; but if those signs be removed, by taking the spark, and the conductor taken from the prime conductor, it will exhibit signs of the contrary electricity. This is a very remarkable phenomenon, but may be accounted for, if the two suppositions be admitted, viz. first, that the electric matter is attracted by conducting bodies; and secondly, that the parts of the electric matter mutually repel each other, the forces of each power being in a certain inverted ratio of the distance.

For the electric matter in an insulated and uniform conductor will then be equally diffused

fused through its whole mass, and the attraction which that conductor will exert on any mass of electric matter presented ab extra must be the excess of the attractive force of the body over the repulsive force of the electricity it contains. Whence a given conductor will attract the electric matter the most powerfully when the quantity it already possesses is the least possible, and its attractive force will decrease as it becomes more saturated with electricity. Let two equal conductors, composed of like matter, be brought within a small distance of each other, then, if the quantities of electricity they contain are equal, the attractions they mutually exert on those quantities will be equal, and it will remain undisturbed in each body. But if one conductor, A, contain more electricity than the other, B, the attractive power of B will be greatest, and will draw the electric matter from A till an equilibrium is obtained. It follows also, that in a number of conducting bodies, communicating with each other, the electric matter will be every where of the same density, if the greatest attractive force of the bodies be supposed equal; but if different

bodies

bodies be supposed to attract the electric matter with different forces, as is most probable, the densities must vary with the forces. This may be called the natural state.

To apply this to the particular instance above-recited, suppose the end of an insulated conductor to be brought near the prime conductor in a positive state, the attractive power of the first-mentioned conductor is greater than that of the prime conductor, yet, not being sufficient to draw sparks, at the given distance, the only effect it can produce is, to make the electric matter accumulate, and become more dense in that part of the prime conductor near which it is presented; by which accumulation the rest of the prime conductor becomes less electrified, as experience testifies. This accumulated body of electricity repels, and consequently rarefies the electric matter naturally contained in that end of the conductor, which is presented to the prime conductor; the rest of the fluid becomes more dense, and the other parts, of the conductor which is presented, exhibit signs of electricity; yet, as this conductor in the whole contains no more than its natural quantity, if
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the electric state be taken off by drawing the spark, and it be afterwards removed from the vicinity of the prime conductor, it becomes negative throughout, by reason of the loss of the spark. If a conductor be presented to the prime conductor in a negative state, the effects are reversed, the attraction being strongest at the prime conductor, and the accumulation being in the conductor which is presented, it exhibits a negative state, which being destroyed, upon removal it becomes positive, by reason of the spark which was given to it when apparently negative.

These effects are more considerable the less the distance is between the two conductors; and the intercedent electric body is peculiarly affected: the manner of which may be better understood, by observing the phenomena of non-electrics, separated by electrics which are less liable to allow the passing of the spark than the air is.

Upon an insulated horizontal plate of metal, lay a plate of glass, considerably larger, so that there may be a rim of three or four inches projecting beyond the metal on every side. Upon the glass lay another plate of metal,

metal, of the same size as the former, so as precisely to cover it. Electrify the upper plate, and the lower will exhibit signs of electricity. Continue the electrization, and the lower plate will emit sparks to an uninsulated body for a time, and afterwards cease. Separate the plates from the glass without un-insulating them, and the glass will appear to be possessed of the contrary electricity on the opposite sides. That side which communicated with the prime conductor during the electrization will have a like electricity, and the other the contrary. Take off the electricity of the plates of metal, and carefully replace the glass on the lower, without destroying the insulation, and also replace the upper plate in like manner. Then, with one end of an insulated wire, not pointed, but rather knobbed at the ends; touch one of the plates, and bring the other end near the other plate: the consequence will be, that a prodigious strong and loud spark will pass between it and the wire, the electricity of the glass will be discharged, and the plates and the wire will still continue unelectrified.

An electric body whose surfaces are thus possessed of the contrary electricities, is said to be charged. The insulation of the lower metallic plate and of the discharging wire is not necessary, except for the purpose of drawing inferences, respecting the manner of charging the electric plate. If the electricity of the prime conductor be very strong, the discharge will sometimes be made by a spark from the one metallic plate to the other, over the surface of the glass which projects on every side; and if the glass plate be thin, in which case it admits of a much higher charge, the discharge will be made through its substance. Glass as thick as one-eighth of an inch, may be penetrated by this means, one or more holes being made where the electric matter has passed, in which holes the glass is pulverized, and may be picked out with a pin.

The greater the surface of the glass, the greater quantity of electricity it will contain, the same density being supposed. But a given machine will not superinduce so strong an electric state on a large plate as a small one: the reason of which seems to be the different spaces of time required in the charging,

conjoined with the different magnitudes of the surfaces at which the electricity is communicated to the air. If there were no escape of the electric matter during the time of charging, the times will probably be as the surfaces of the plates, equal thicknesses being always supposed; and if two plates were equally charged, the escape would perhaps be likewise as the surfaces. These being premised, the whole escape will be as the time of charging, and the surfaces of each conjointly, that is, because the times are as the surfaces, in the duplicate ratio of their surfaces directly. Hence it appears that the escape in plates, that increase in size, approaches rapidly and continually nearer to the quantity of electricity supplied by the machine, and that the more powerful machine, by diminishing the time of charging, will charge higher in the inverse proportion of the time, so much escapement being saved. It must be confessed that the suppositions not being accurate, the ratios are only nearly true, yet this way of considering the subject serves to indicate the causes, though not strictly to measure the effect.

From the above related experiment, of separating the glass from the plates of metal, it is shewn that the surplus of the electricity on one surface, is precisely equal to the deficiency on the other; for if it were otherwise, the plates and the discharging wire would become possessed of the predominating electricity. It also shews that if the theory of positive and negative electricity be true, electric bodies must contain the electric matter, for the electric states are evidently on the surfaces of the glass independent of the metal: now though we can conceive that a positive state may be superinduced by an accumulation of electricity on one surface, yet it is absurd to suppose that the electric matter can be emitted and exhausted from the other side, if it did not exist there, previous to such emission and exhaustion. From this we have ground to conclude that all bodies, as well electrics as non-electrics, do attract the electric matter, but that electrics, being so constructed as not to admit it into their substance, as non-electrics do, do condense it upon their surfaces, and at all times hold a great quantity so condensed. And if the quantity of electri-

city be increased or diminished on one side, the electricity on the other surface must be rarefied or condensed in consequence of the diminution or increase of the whole attractive force of the body, as explained in the beginning of this chapter. The effects will also be more considerable the less the distance is between the two surfaces.

It is not possible to charge an electric plate by inducing an electric state on one of its surfaces, unless the other be at the same time sufficiently near to an uninsulated non-electric to assume the contrary state by emitting or receiving the electric matter.

If a plate of glass be laid upon an uninsulated plate of metal, the upper surface may be rendered electric by friction, or by applying an electrified body successively to its parts. This electricity may be taken off by touching the upper surface with an uninsulated metallic plate of the same dimensions as that upon which the glass is placed, but will not be entirely taken off, because the communication between the two surfaces in this method is not perfect, and because the metal cannot, by ordinary means, be brought into actual contact

tact with the glass. The small quantity which remains, produces an effect which has been mistaken for a perpetual electricity. For if a plate of metal, to which a glass handle is affixed, be laid upon the glass, this small quantity of electricity will influence the metal, and, without actually communicating the electric matter, will cause it to exhibit a similar state, upon the principle explained at the beginning of this chapter. If this be taken off, by drawing the spark, and the metal then removed, by means of the glass handle, it will be found possessed of the contrary state of electricity, and another spark may be produced. The metal plate may be then again applied to the surface of the glass, and the process again repeated, and so on for a prodigious number of times, without any sensible difference in the event. For the electricity at the surface of the glass being almost in the natural state, as to condensation, does not disappear for a very long time, and the very near approach of the metal enables it to produce the same effect as would be obtained at a greater distance from a stronger electricity. This is made obvious by bring-

ing the metallic plate near the surface of the glass before its first strong electricity is taken off, for the same event is perceived at the distance of four, five or six inches as in the former case was produced by contact.

The vapors of the atmosphere are continually attaching themselves to the surface of cold glass, and by that means destroy the electricity. Sulphur, wax or resin, being less subject to this, retain their electric state much longer. A plate of glass or wood, coated over with any substance of this nature, may be excited by friction, and will produce electricity in a metallic plate, in the manner above described for a very great length of time. Such a plate, together with its metal, has been named the *electrophorus*.

If the discharge of an electrified plate be made by the parts of a living animal, a considerable pain will be felt chiefly at the extremities of the muscles. For example, if a man touch the lower metal plate with one hand, and bring the other to the upper plate, at the instant of the emission, he will feel a pain at the wrists and elbows, which as instantly vanishes. If a larger glass plate be
used,

ased, the pain will be felt in the breast; if yet larger, the sensation will be that of a universal blow. This sensation has obtained the name of the shock, and will deprive animals of life, if sufficiently strong. The shock from a square foot of glass in contact with metal, will sometimes instantly kill mice, sparrows, and the like, but sometimes only throws them into universal convulsions, of which they in general recover. Six square feet of glass will deprive a man of sensation for a time, if the head be made a part of the circuit through which the electricity moves. No inconvenience has been found from the electric shock by men of strong habits, but women of delicate constitutions have had convulsions after a violent shock. We may observe that the electric shock is a proof that the electric matter passes through the substance of non-electrics, and not over their surfaces alone, as some have supposed.

C H A P. V.

Of Electric Jars; the Velocity of the Shock; Light in the Boylean Vacuum; the charging a Plate of Air, whence is deduced the Action of Pointed Bodies; and of the Electricity which is produced in certain Bodies by heating and cooling.

FOR the sake of simplicity and precision, we have related the effects of electrifying glass-plates, which however are little used. The object of the philosopher in general is to collect a large quantity of electricity, by means of the surfaces of electrics, and it is neither necessary nor convenient to use flat plates. The electrician therefore accommodates himself with a sufficient number of prepared jars. They are made of various shapes and magnitudes, but the most useful are thin cylindrical glass-vessels, about four inches in diameter, and fourteen in height: these are coated within and without, with tinfoil, which is stuck on with gum-water, excepting two inches of the

the rim or edge, which is left bare, to prevent the communication between the coatings. About four inches from the bottom, within, is a large cork, through which is inserted a thick wire, ending in several ramifications, which touch the inside coating; the upper end of the wire terminating with a knob, considerably above the mouth of the jar. See fig. 139. letter S. When it is required to be charged, it may be held in the hand, or on an uninsulated table, and the knob of the wire applied to the conductor; the inside coated surface becomes possessed of the electricity of the conductor, and the external surface acquires the contrary electricity by means of its uninsulated coating. When a jar of this kind is highly charged, it will discharge spontaneously over the uncoated surface, and seldom through the glass, whereas, when the uncoated surface is large, they are more apt to break by that means, and become useless. Yet, there is no dependance that a jar which has discharged itself over its surface will not at another time break by a discharge through the glass, as the contrary often happens.

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When a greater degree of electric force is required, larger jars must be used, in which the form is of no consequence, farther than convenience requires. But it is less expensive, and quite as effectual, to use a number of smaller jars, so that the quantity of coated surface may be the same as in the large jars. In this case, a communication must be formed between all the outside coatings, which may be done by placing them on a stand of metal; and also between all the inner coatings, which is best done by means of wires. Such a collection is called a battery, and may be charged and discharged like a single jar.

In discharging electrical jars, the electricity goes in the greatest quantity through the best conductors, and by the shortest course. Thus, if a chain and a wire, communicating with the outer coating, be presented to the knob of a jar, the greater part of the charge will pass by the wire, and very little by the chain, which is a worse conductor, by reason of its discontinuation at every link. When the discharge is made by the chain only, sparks are seen at every link, which is a proof that they are not in contact; and as the chain must be stretched

stretched by a considerable force before the sparks cease to appear on the discharge, it follows that there is a repulsive power in bodies, by which they are prevented from coming into contact, unless by force, as has been observed in the former part of this treatise.

By accurate experiments it appears, that the force of the electric shock is weakened, that is, its effects are diminished, by using a conductor of a great length in making the discharge. Yet, a very considerable shock was given by the Abbé Nolet, in the presence of the French King, to one hundred and eighty men; the first of whom formed a communication with the outer coating, the rest joining hands in a circular line, and the last touched the knob of the inner coating. They were all shocked at the same instant. Dr. Watson, and many other gentlemen of eminence in the philosophical world, were at the pains of making experiments of the same kind, but much more accurate. They found, by means of wire insulated on baked wood, that the electric shock was transmitted instantaneously through the length of 12276 feet.

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When any animal or substance is to be subjected to the shock, it is usually done by means of two chains, one of which connects one extremity of the animal or substance with the outer coating, and the other being fastened to, or laid on, the other extremity, is applied to the knob of the inner coating to make the discharge. The animal or substance thus forming a part of the circuit, receives the whole shock. The strong shock of a battery will melt wire of the seventieth of an inch in diameter, and wires of less diameters are frequently blown away, and dispersed. Gunpowder may be fired by a charge of three square feet; the method is, to put it into a quill, and thrust a wire into each end, so as not to meet, and then make these wires a part of the circuit. Spirit of wine, ether, and a mixture of common and inflammable air, may also be fired by the same means, or even by the spark from the conductor. Yet, it seems probable in these cases, that inflammation does not take place because the electric matter is fire, or in an ignited state, but because the extreme velocity of its motion excites those vibrations in which heat consists, or at least which always accom-

panies

panies it. A strong shock gives polarity to small needles.

Electricity will pass by means of non-electrics that are so small as to be destroyed by its passage, as has just been instanced in wires: the force of the explosion in these instances is very considerable, and is termed the lateral force of electricity. The following is a proof of this, and may be exhibited with less than a square foot of coated glass, if well charged. At the glass-house there is generally a great number of solid sticks of glass, about a quarter of an inch diameter; if these be examined narrowly, several of them will be found to be tubular for a considerable length, but the diameter of the cavity seldom exceeds the 200th part of an inch. Select these, and break off the tubular part, which may be filled with quicksilver by sucking; care being taken that no wet previously insinuates itself, and then send the shock through this small thread of quicksilver, which will instantly be dislodged, and will break or split the tube in a curious manner.

An experiment similar to this may be made with a glass-tube filled with water. Take a
small

small glass-tube, whose cavity is about a quarter of an inch in diameter, fill it with water, and stop the end with soft pomatum: thro' the pomatum insert two wires, that they may almost touch each other, and make their ends a part of the circuit in the discharge of a strong shock, from about two feet square of coated glass; the consequence will be, that the water will be dispersed in every direction, and the tube blown to pieces, particularly in the middle, near the discontinuation of the wire: the ends with the wires and pomatum will sometimes be found undisturbed. This is a striking instance of the velocity and force with which the electric matter is moved.

This property, of being charged and discharged, is not peculiar to glass, but is common to all other electrics.

If a thin bottle be exhausted of air by means of the air-pump, it will receive a considerable charge by applying its bottom to the electrified prime conductor, during which time the electric matter will pass thro' the vacuum between the hand and the inner surface of that part of the glass which is nearest the prime conductor. This appearance, whose cause has already been

in some degree explained, is exceedingly beautiful in the dark, especially if the bottle be of a considerable length. It exactly resembles those lights which appear in the northern sky, and are called streamers, or the aurora borealis. If one hand be applied to the part of the bottle which was applied to the conductor, while the other remains at the neck, the shock will be felt, at which instant the natural state of the inner surface is restored by a flash, which is seen pervading the vacuum between the two hands.

The electric shock may be given from a plate of air, by means of two large plates of metal, or rather boards covered with tinfoil; one of which is to be suspended to the prime conductor, and the other placed parallel to it on an uninsulated stand, at a convenient distance. These boards may be regarded as the coatings of the plate of air contained between them, and if a communication be formed between them, by touching the uninsulated board with one hand, and applying the other hand to the conductor, the shock will be felt accordingly. It is almost unnecessary to observe, that if the electricity be powerful, or the distance between

tween the plates small, the charge will pass from the one to the other in a spark through the air.

If we compare this experiment with what has already been observed respecting the charging and discharging electric bodies, it will appear that most of the electric phenomena are the consequences of the air being charged. Thus, the prime conductor imparts its electricity to the surface of air immediately contiguous, and when the spark is drawn the discharge is made to the non-electrics, namely, the floor and wainscot of the room, which are in contact with the opposite surface. The charge of electrics has already been observed to be greater, the nearer the surfaces are to each other; thus, glass beyond half an inch thickness cannot be charged by our machines: in like manner, the discharge, that is to say, the spark from the conductor, will be greater, when a large company stand about it than at other times, the body of air which is interposed between the conductor and the nearest uninsulated non-electrics being then less in thickness than at other times. It follows also, that a large conductor will give a larger spark than a less; the discharge being from a surface proportionally

tionally greater. And since this discharge consists chiefly of the electric matter, residing at, or near the surface of contact, and little, if at all, of that which may be within the substance of the conductor, it is of no consequence whether the conductor be a solid non-electric or hollow, provided the surface be unaltered in form and magnitude. Hollow cylinders of copper, or tin, or wood, covered with tinfoil, or strongly gilt, are the conductors generally in use; and in the other circumstances we have here related by inference, experience agrees with our conclusions.

It is a consequence of the air being charged that broad non-electric surfaces draw large sparks from the conductor; for the sparks are the discharges of a large plate of interposed air. A less surface will draw a less spark, but because the same machine charges less surfaces higher than greater, the spontaneous discharge through the body of the electric air will be made at a greater distance of the surfaces, that is to say, the sparks will be longer. If the surface of the non-electric presented be yet less, the sparks, by the same reason, will be less, and emitted to a still greater distance.

And if the surface be indefinitely small, or, in other words, if the non-electric be pointed, the spark may be so small as to be invisible, and the distance to which it can be emitted may be unlimited. The effect of pointed bodies seems to depend on circumstances of this nature; but the reason of the different appearances of the light on points electrified, positively or negatively, still remains a difficulty. It would not, indeed, be difficult to frame an hypothesis for the purpose of removing it, but it is safer to wait till the business is accomplished by observation and experiment.

Since attraction and repulsion are circumstances which, in almost every situation, attend bodies in an electric state, philosophers avail themselves of these phenomena to discover the state and degree of electricity. The electrometer *rp*, in fig. 139. indicates the state of the conductor by the distance to which it elicits the spark; but it has the inconvenience of carrying off the electricity at the instant in which it becomes useful; and is, besides, totally improper for denoting small degrees of intensity. Its chief application is to give a
number

number of shocks of precisely the same force. Small degrees of electricity are very well shewn by the divergence of two fine hempen-threads, suspended together from the conductor. If little balls of pith or cork be fastened to the ends of the threads, they will serve to denote still greater intensities, as they will not so soon arrive at their utmost divergence by the mutual repulsion. Fig. 140. is a very useful electrometer upon this principle. It consists of an upright stick of box-wood, *a b*, on one side of which is affixed a graduated semi-circle; *d* is a ball of pith or cork, and is stuck upon the end of a small rod or radius of wood, which, by means of a small axis at *c*, is moveable in a plane parallel to that of the semi-circle. This electrometer is fixed upright on the prime conductor; the radius must therefore hang perpendicularly down when it is not electrified; and according to the intensity of the electric state given to the conductor, the repulsion must cause the ball to ascend. The ascent will be marked by the graduations.

This last electrometer, though by far the most useful of any, is considerably imperfect.

It is much more sensible of small variations in the electric force when at the beginning of the graduations than any where else, and is not reducible to a standard, that is to say, two electrometers will not agree, though equally electrified. This last imperfection is common to every instrument which has yet been invented for the purpose of measuring the intensity of electricity.

These methods serve to estimate the force of the electric repulsion, but do not indicate whether the electricity be positive or negative. If the electricity be strong, the nature of its state may be known by presenting an uninsulated metallic point, which will be illuminated or tipped, with a light corresponding with the contrary electricity to that of the conductor. (See p. 378.) To discover the nature of smaller degrees of electricity, a downy feather may be insulated by suspending it by a slender silk-thread, and then rendered electric, by bringing it in contact with the cylinder or conductor of the machine. The feather in this state will be repelled by bodies which possess the same kind of electricity as itself, and will be attracted by all other bodies.

We shall finish our general account of artificial electricity with pointing out some of the other means by which it may be acquired; but which the theory we at present possess is too imperfect to explain.

Sulphur melted in an earthen vessel, and placed to cool upon uninsulated conductors, is strongly electric when taken out, but is not so when it has stood to cool upon electric substances.

Sulphur melted in a glass-vessel acquires a strong electricity in the circumstances above-mentioned, whether the vessel be placed on electrics or not; but stronger in the former case. This electricity is yet stronger, if the glass be coated with metal. In these cases the glass is always positive, and the sulphur negative. It is particularly remarkable, that the sulphur acquires no electricity till it begins to cool and contract, and is the strongest at the time of the greatest contraction; whereas the electricity of the glass is at that time weakest, and is the strongest of all when the sulphur is shaken out before it begins to contract, or has acquired any negative electricity.

It has been observed, that silk or worsted stockings become electrical after being worn some hours, more particularly the silk, as does also a beaver-shirt worn between two others. If a white and a black silk-socking be worn on the same leg, they obtain contrary electricities. When drawn off together they shew very little signs of electricity, but, upon separating them, each indicates an electrical state so strongly, that the repulsion inflates them, so as to exhibit the intire shape of the leg. If the two stockings be allowed to come together, they strongly attract each other, the inflation subsides, and they stick very closely together; in which situation they retain their electric state, notwithstanding the approach of the sharpest metallic point. A second separation again exhibits their respective electricities as before; and this may be done several times without much diminishing their electricities. The electricity of the black stocking is negative, and of the white positive.

The tourmalin is a hard pellucid gem, of a red colour, and is brought from the island of Ceylon by the Dutch. It possesses the property of assuming an electric state if heated;

one

one side of it becoming positive, and the other negative. If this electric state be taken off by contact, the stone will become electric as it cools; but with this difference, that the side, which, during the heating was positive, will now be negative, and the other side positive, which before was negative. But if the electric state be not taken off, the same kind of electricity will be found on the same side during the whole time of heating and cooling. Either side of the tourmalin will become positive by friction, and both may be made so at the same time.

These are the chief properties of this very remarkable stone, which are also common to the Brazil topaz, and some other gems. There are several important particulars relative to this and every other branch of electrical knowledge, which cannot be enumerated and described, in an introductory book, on account of the great length of detail they would require. For these, the student must have recourse to treatises written expressly on this subject. There are also a number of fanciful and pleasing variations of the common experiments. Bells are rung by an insulated clapper, which is

alternately attracted and repelled between two bells in opposite states of electricity ; figures of men and women cut in paper are made to dance by the attraction and repulsion between two metallic plates ; light mills of pasteboard are driven round by the current of air from electrified points, &c. &c. particular accounts of all which may be had in pamphlets, which are frequently sold by the makers of the electrical apparatus.

C H A P. VI.

*Of Natural Electricity; and of the Identity of
Lightning and the Electric Matter.*

THAT electricity is no trivial or confined subject, must appear from what has already been said, since there is no body in nature that is not acted upon by it, either as a conductor or non-conductor. The importance of the electric matter in the mundane system is more particularly confirmed by observations on those phenomena which take place without the concurrent operation of man. Of these it will be proper to give some account.

Several fishes possess the property of giving the electric shock. The torpedo, or numbing fish, and one or more species of eels, from Surinam, if touched by the hand, a metal rod, or any other conductor, give a considerable shock to the arm, but may be safely touched by means of a stick of sealing-wax. The shock depends on the will of the fish, and is transmitted to a great distance, so that if persons

sons in a ship happen to dip their fingers or feet in the sea, when the fish is swimming at the distance of fifteen feet, they are affected by it.

But the most remarkable appearances of electricity, which are viewed with surprise and admiration by all ranks of people, are those which may be termed atmospherical, as for the most part existing in, or depending on the state of the atmosphere. Lightning is proved to be an electric phenomenon, and there is little doubt but the aurora-borealis, whirlwinds, water-spouts, and earthquakes, depend on the same principle.

The resemblance between the electric spark and lightning, is so obvious, that we find it among the earliest observations on the subject; but the proof of the important theorem of their identity was reserved for Dr. Franklin, who is so justly celebrated for his many discoveries in this branch of physics. He first observed the power of uninsulated points, in drawing off the electricity from bodies at great distances, and thence inferred that a pointed metallic bar, if insulated at a considerable height in the air, would become electrical by communication from the clouds during

ing a thunder-storm. He gave this thought to the public; and several machines, consisting of insulated iron bars, erected perpendicular to the horizon, and pointed at top, were set up in different parts of France and England. The first apparatus that was favored with a visit from this ethereal matter, was that of Mons. Dalibard, at Marly la Ville, about six leagues from Paris. It consisted of a bar of the length of forty feet, and was electrified on the tenth of May, 1752, for the space of half an hour, during which time the longest sparks it emitted measured about two inches.

Dr. Franklin, after having published the method of verifying his hypothesis concerning the sameness of electricity with the matter of lightning, was waiting for the erection of a spire in Philadelphia to carry his views into execution; not imagining that a pointed rod of a moderate height could answer the purpose; when it occurred to him, that by means of a common kite he could have a readier and better access to the regions of thunder, than by any spire whatever. Preparing therefore a large silk handkerchief, and two cross sticks

of

of a proper length, on which to extend it; he took the opportunity of the first approaching thunder-storm, to walk into a field in which there was a shed convenient for his purpose. But, dreading the ridicule which too commonly attends unsuccessful attempts in science, he communicated his intended experiment to nobody but his son, who assisted him in raising the kite.

The kite being raised, the end of the string being tied to a silk string which he held in his hand, and a small key being fastened at the place of junction, a considerable time elapsed before there was any appearance of its being electrified. One very promising cloud had passed over it without any effect; when, at length, just as he was beginning to despair of his contrivance, he observed some loose threads of the hempen string to stand erect, and to avoid one another just as if they had been suspended on a common conductor. Struck with this promising appearance, he immediately presented his knuckle to the key, and, let the reader judge of the exquisite pleasure he felt at that moment, the discovery was complete. He perceived a very evident
electric

electric spark. Others succeeded, even before the string was wet, so as to put the matter past all dispute, and when the rain had wetted the string, he collected the electricity very copiously. This happened in June 1752, a month after the electricians in France had verified the same theory, but before he had heard of any thing they had done.

The grand practical use which the Doctor made of this discovery, was to secure buildings from being damaged by lightning, a thing of vast consequence in all parts of the world, but more especially in several parts of North America, where thunder-storms are more frequent, and their effects, in that dry air, more dreadful, than they are ever known to be with us.

This great end is accomplished by so easy a method, and by so cheap and seemingly trifling apparatus, as fixing a pointed metalline rod higher than any part of the building, and communicating with the ground or rather the nearest water. This wire the lightning is sure to seize upon, preferably to any other part of the building, unless it be very large and extended, in which case wires may be erected

erected at each extremity; by which means this dangerous power is safely conducted to the earth, and dissipated without doing any harm to the building.

Conducting rods are now become very common, both for the purpose of securing buildings, and of making observations on the state of the atmosphere. The best of those which are intended for the latter purpose, is the following. On the top of any building, which will be the more convenient if it stand upon an eminence, erect a pole as tall as a man can manage without difficulty, having on the top of it a solid piece of glass or baked wood, a foot in length. Let this be covered with a tin or copper vessel in the form of a funnel, to prevent its ever being wetted. Above this let there rise a long slender rod, terminating in a pointed wire, and having a small wire twisted round its whole length, to conduct the electricity the better to the funnel. From the funnel, let a wire descend along the building about a foot distance from it, and be conducted through an open sash into any room which shall be most convenient for managing the experiments. In this room
let

let a proper conductor be insulated and connected with the wire coming in at the window. This wire and conductor, being completely insulated, will be electrified whenever there is a considerable quantity of electricity in the air; and notice will be given when it is properly charged, either by the mutual repulsion of two small balls of cork hung to it by threads, or by the ringing of two small bells, the one suspended from, and communicating with the conductor, and the other uninsulated: these bells will be in opposite states of electricity when the conductor is electrified, and if a clapper or small metallic ball be hung by a silk thread between them, it will be alternately attracted and repelled by each, and consequently indicate the electricity of the conductor by ringing.

To make these experiments in perfect safety, the electrified wire should be brought within a few inches of a conducting rod, which serves to guard the house, that the redundant electricity may pass off that way, without striking any person who may happen to stand near it. The conductor to guard the house should consist of a rod, without breaks or discontinuities,

continuities, between one fourth and one half of an inch thick, if it be of iron, but smaller if it be brass or copper, terminating upwards in a sharp point about four or five feet above the highest part of the building: it is convenient that this point be gilt, to preserve it from rusting. The lower end of the rod should, if possible, be continued to some well or running water, or otherwise it should be sunk several feet into the ground, at the distance of some yards from the building. It is of no consequence how many bendings are made in the rod, but it is much better to fasten it to the outside than the inside of the building: for these conductors are known to emit sparks during thunder-storms, notwithstanding their insertion in the earth, from which fatal consequences may be apprehended when the electric force is very great.

It is clear, from many instances, that the lights which are seen at the mast-heads of ships, and on the vanes of some churches during thunder, owe their origin to the electric matter passing by means of uninsulated points.

The polarity of the compass-needles has been known, in several instances, to be destroyed

stroyed, or reversed by lightning. An effect which, as has been observed, may be produced *in parvo* by the electric shock from glass.

If the electrician be desirous of making experiments upon the electricity of the atmosphere to greater exactness, he must raise a kite, by means of a string in which a small wire is twisted. The lower extremity of this line must be silk, and the wire must terminate in some metallic conductor of such a form as shall be thought most convenient. But it is dangerous to raise it upon the approach of a thunderstorm; and upon this occasion the common apparatus for drawing electricity from the clouds will probably answer every intended purpose.

C H A P. VII.

Of Lightning, and other Meteors.

TO know that lightning and the electric matter are the same, is a very capital advance in natural philosophy, but we must still remain ignorant of the causes of many of the appearances which accompany lightning, so long as our acquaintance with the properties of electricity is so very imperfect. We know that the clouds are almost always electrified, sometimes positively, and sometimes negatively; but whence, or by what means they acquire that state; whether by the heating or cooling of the air, upon the Tourmalin principle, whatever that may be, or whether the clouds be only the conductors by which the electric matter is conveyed through the air, from places in the earth where it is redundant to other places where there is a deficiency, cannot easily be determined. The first is the conjecture of the well known Mr. Canton, and the latter is the chief proposition in the theory of that great philosopher Sig. Beccaria of Turin.

It

It is probable that both circumstances may conduce to the effect; the heating or cooling of the air may produce, or rather collect, that electricity which is so great an agent in atmospherical events, and its discharge may be effected in the manner in which Signior Beccaria has, with great probability, supposed it to be accomplished.

A thunder-storm usually happens in calm weather. A dark cloud is observed to attract others to it, by which it continually increases in magnitude and apparent density. When the cloud is thus grown to a great size, its lower surface swells in particular parts towards the earth, sometimes by light flimsy clouds, and sometimes by an inferior protuberance. During the time that the cloud is thus forming, flashes of lightning are seen to dart from one part of it to the other, and often to illuminate the whole mass; and small clouds are observed moving rapidly, and in very uncertain directions beneath it. When the cloud has acquired a sufficient extent, the lightning strikes the earth in two opposite places; the path of the lightning lying through the whole body of the cloud and its branches.

That thunder-clouds do nothing more than conduct the electric matter from one place to another, is not only probable, on account of its striking in two places, but likewise from the consideration, that the emission of the flash would destroy the electric state of the clouds, if it were not immediately recruited from some other part. But the electric state is not destroyed after a flash, if we may judge either from the electric apparatus, or from the cloud itself; for the first appears to be not less electrified, and the latter is the next moment ready to make as great a discharge as before. Besides, If the two flashes of lightning, which strike at different places, nearly at the same time, were simple, similar and independent discharges of the cloud, why should they resemble each other? and yet they do very much, as appears by observing a thunder-storm at a distance. Then it is seen, that if one part of the cloud give a single flash, the other extremity will give, or rather receive, a single flash a short time or the instant after; but if it give two, three, or four quick successive flashes, the other extremity will receive a like number a little, but very perceptible time after. The angular distance

tance between the places of these correspondent flashes is frequently four or five points of the compass.

It is remarkable, that most detached clouds, whose angular heights are but small, and which consequently may be viewed in profile, are variously arched at their upper surface, while their under surface is horizontal. This appearance is particularly observable in thunder-clouds, and also takes place in the smoke of resin, or steam of water, electrified by the common machine.

Whatever may be the cause that disturbs the equilibrium of the electric matter in the atmosphere, it may easily be conceived, that when such disturbance happens in the upper, and highly rarefied regions of the air, the equilibrium will be restored by dartings and electric coruscations through the vacuum, similar to those exhibited in the vacuum of the air-pump. This consideration accounts for the aurora borealis, which has commonly a motion of darting or undulating between two opposite parts of the heavens.

In clear and calm weather, when the electricity is not very strong, it may pass through

the air without bringing any great quantity of vapours into its course, and, according to the conductors it meets in the air, it will sometimes be rendered visible for small parts of its passage, and occasion those appearances which we call shooting-stars. It is observable, that shooting-stars are usually very low in the air, and that in general they all direct their course the same way.

The ignis fatuus, or Will-with-the-wisp, is a luminous meteor that seldom appears more than six feet above the ground. It is found chiefly about bogs, and is always in motion, varying both its figure and situation in a very uncertain manner. In the plains in the territory of Bologna, they are frequently very large, and give a light equal to a torch; and there are some places where one may be almost sure of seeing them every dark night. The most probable conjecture concerning these meteors is, that they consist of inflammable air which has been kindled by electricity.

Speaking of water-spouts, we observed that the convergence of winds and their consequent whirling motion, was a principal cause in producing that effect; but there are
appear-

appearances which can hardly be solved by supposing that to be the only cause. They often vanish, and presently appear again in the same place: whitish or yellowish flames have sometimes been seen moving with prodigious swiftness about them, and whirlwinds are observed to electrify the apparatus very strongly. The time of their appearance is generally those months which are peculiarly subject to thunder-storms, and they are commonly preceded, accompanied or followed by lightning, the previous state of the air being similar. And the long established custom, which the sailors have, of presenting sharp swords to disperse them, is no inconsiderable circumstance in favor of the supposition of their being electrical phenomena. Perhaps the ascending motion of the air, by which the whirling is produced, may be the current which is known to issue from electrified points, as the form of the protuberance in the sea is somewhat pointed; and the electrified drop of water, heretofore mentioned, may afford considerable light in explaining this appearance.

It is extremely probable that earthquakes owe their original to the discharge between

a cloud and the earth, in a highly electric state. They happen most frequently in dry and hot countries, which are most subject to lightning and other electrical phenomena; and are even foretold by the electric coruscations and other appearances in the air, for some days preceding the event. Earthquakes are attended by no fire, vapor, or smell, which however could hardly fail to appear, if the common opinion, of their being occasioned by a subterraneous explosion, were true. The effect of an explosion of this nature would be a gradual lifting of the earth, after which it would fall again, and, no doubt, destroy or change the course of springs, and considerably alter the face of the country: the contrary to all which is true; for, as far as observation can determine, the shock of an earthquake is instantaneous to the greatest distances, and seldom does more mischief than overthrowing buildings. Earthquakes are usually accompanied by rain, and sometimes by the most dreadful thunder-storms. All these and many more circumstances, but especially the almost instantaneous motion of the shock, induce us to look for their cause in electricity, the only
power

power in nature that acknowledges no sensible transition of time in its operations.

Dr. Priestley, in his *History of Electricity*, has given an abridgment of Dr. Stukely's observations and inferences on this subject, and has himself shewn by experiment, that the electric shock causes a vibration similar to that of an earthquake, when it passes at or near the surfaces of bodies.

We here conclude with observing, that the knowledge we have of the properties of electricity has been acquired, for the greater part, within the last half-century; and that if discoveries proceed as rapidly as they have began, we may hope that a similar period will afford a more perfect acquaintance with the causes not only of atmospherical events, but of magnetism, of vegetation, of muscular motion, and other appearances, in which, it is more than probable, this great and active power has a share.

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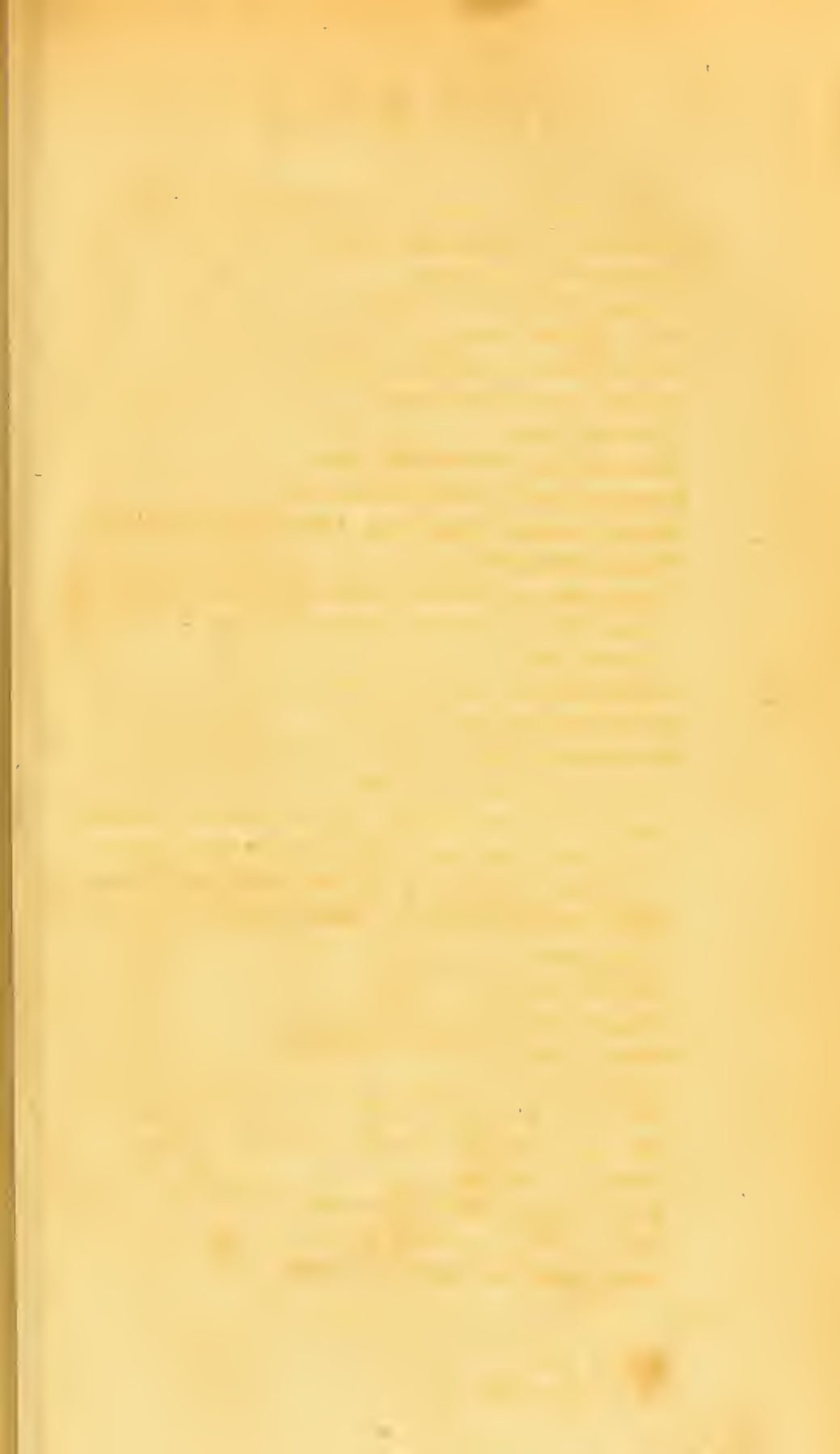
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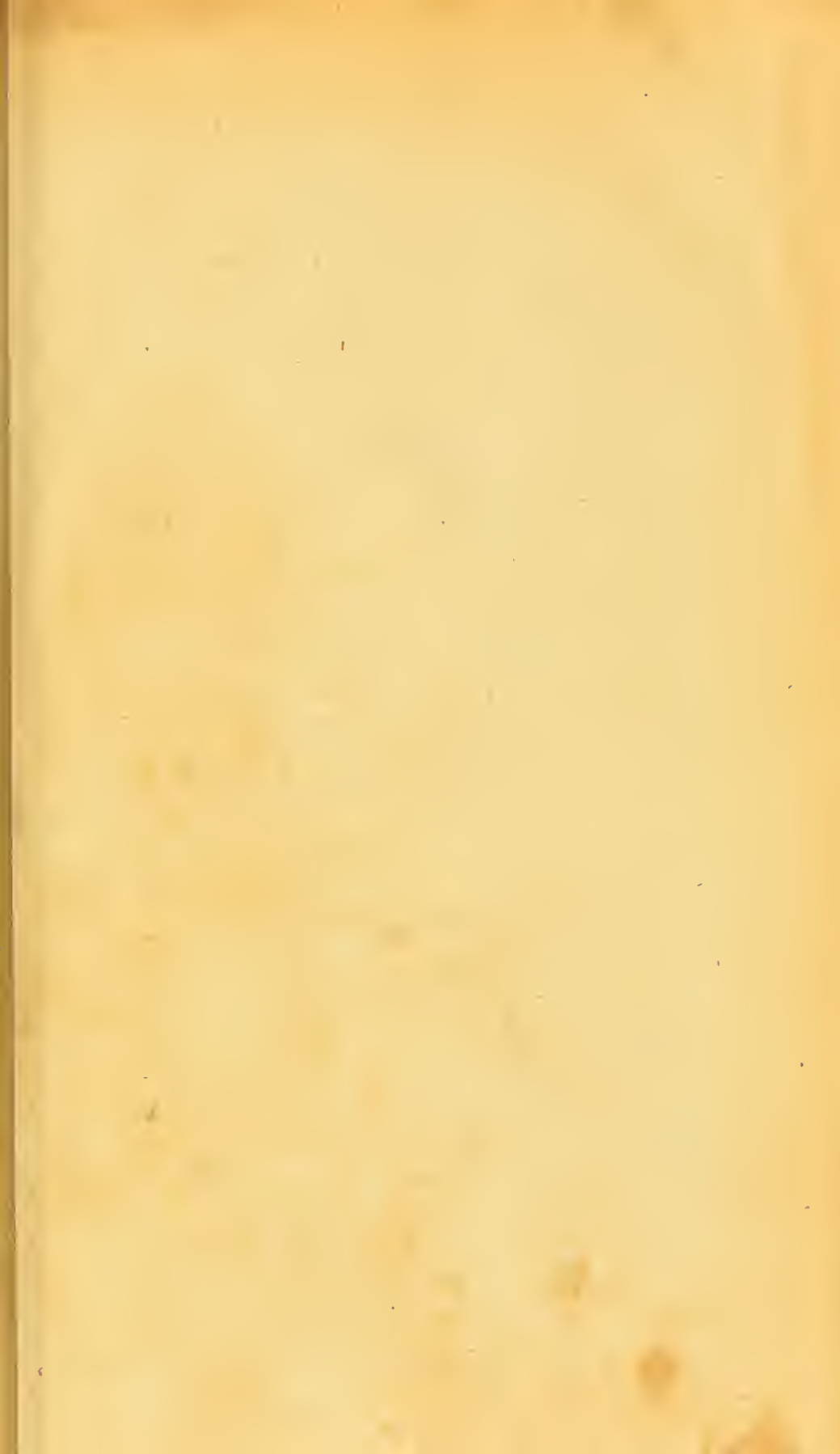
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